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ON THE COVER:

The successful launch of Navigation Technology Satellite 2 (NTS-2), the first NAVSTAR GPS satellite, marked the beginning of a new era in navigation and timekeeping history. Developed by the Naval Research Laboratory, NTS-2 was launched on 23 June 1977 aboard an Atlas F launch vehicle from the Vandenberg Air Force Base Launch Complex in California.

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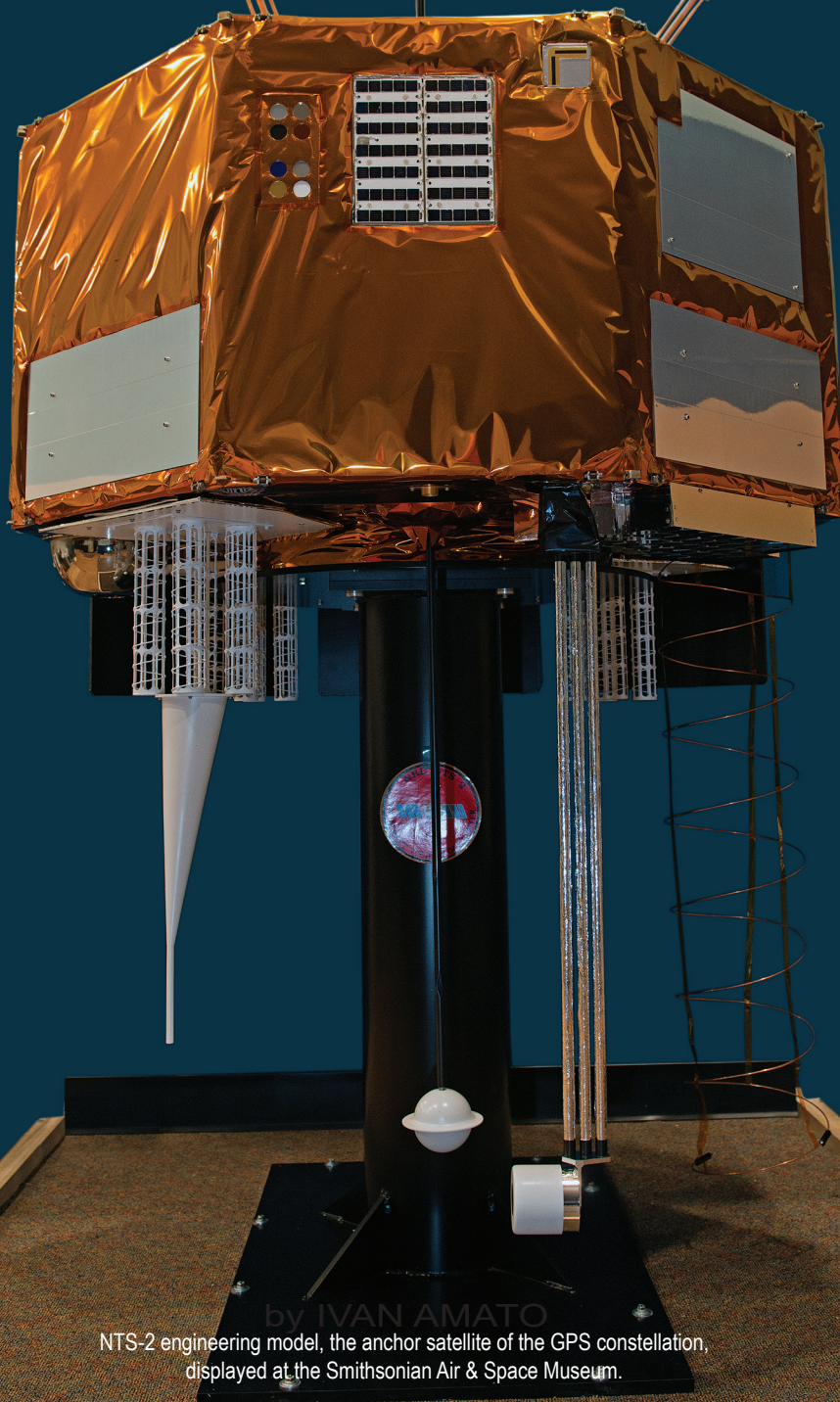


IVAN AMATO

In the summer of 1923, on a bucolic plot of land along the Potomac River where it cuts southward through the bottom of the District of Columbia, a few of the twenty founding radio researchers of the newly opened Naval Research Laboratory already were craning their necks toward space. This first generation of NRLers, who commuted to the laboratory on dirt roads and by boat from Virginia just across the Potomac, could not have known it then, but their militarily significant interest in the upper atmosphere's effects on long-distance radio communication would set the lab on a path to becoming one of the most consequential players in the gestation, birth, and maturation of the Space Age. From these personal and institutional roots in the 1940s and 1950s would emerge a culture of innovation that for the rest of the 20th century, and into the 21st, would lead to some of the highest of high technologies. These include the world's first spy satellite, a portfolio of space-based intelligence, surveillance, and reconnaissance (ISR) capabilities; the Global Positioning System (GPS) for planet-wide navigation and time synchronization (without which Internet and cell phone communication would be shadows of what they are); and battlefield technologies that sometimes played world-changing roles as they were deployed in the Cold War and in every phase of war and peace since. In the 1980s, the Department of Defense would acknowledge NRL's preeminent role in developing defense-related space technologies by designating the lab to be the home of the Naval Center for Space Technology. This book chronicles the people, personalities, and institutional, political and geopolitical influences that together have woven into one of the country's great places of innovation.

Taking Technology Higher

*The Naval Center for Space Technology
and the Making of the Space Age*



by IVAN AMATO
NTS-2 engineering model, the anchor satellite of the GPS constellation,
displayed at the Smithsonian Air & Space Museum.

Cleared for public release.

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Mr. Christopher Dwyer
Superintendent, Space Systems Development Department

FOREWORD

December 2018

If you are a space professional who has spent most of your life in the civilian side of the business—human spaceflight, space science and astronomy, telecommunications, environmental monitoring—then it is entirely possible that you have barely, if ever, heard of the Naval Center for Space Technology at the U.S. Naval Research Laboratory. Yes, you might recall a mission called “Clementine” that in the mid-1990s took the first pictures of the moon since the time of Apollo and, by the way, discovered deposits of ice at the lunar poles. After all, this was a discovery that, in its time, made it to the NBC “Today” show. And so you might even recall that it was, surprisingly, sponsored and managed by the Department of Defense Strategic Defense Initiative Office, the “Star Wars” missile defense program created by President Reagan a decade earlier. But you are very unlikely to know, or to remember if you once knew, that the spacecraft itself was built and the mission was flown by NRL.

If your career has been in the national security space business, then you are much more likely to know about NRL and NCST, but still it will not be uppermost in your thoughts. The typical insider’s perception of the national security space program is much like that of an intelligent layman who is in touch with current events: the United States operates numerous imagery and electronic intelligence (ELINT) collection satellites, managed by an amorphous group of “three-letter agencies” such as NSA, NRO, CIA, and NGA. The Air Force is somewhere in the mix, because their logo is on the launch vehicles that might get a 5-second sound bite on network news when a new “bird” goes up. But few even in the intelligence community spend much time thinking about the Navy’s or NRL’s role, or remember GRAB and Poppy—the first ELINT spacecraft—if indeed they ever knew of them.

The development of satellite-based navigation follows a similar pattern. GPS and its multitude of applications are today so ubiquitous, so embedded in the fabric of daily life, that if GPS is noticed at all by the general public it is regarded as a public utility, likely known only by its acronym. Few who use the term even know what the letters represent, and almost no one knows that the history of satellite navigation is a Navy history, for both GPS and the lesser-known system which preceded it, TRANSIT, originated in Navy laboratories. In particular, without NRL’s pioneering concept for precision time-based navigation and the proof of that concept with the Timation mission, the USAF-managed development of today’s GPS constellation would not have occurred.

There is a recurring theme here: at NRL, the Navy operates the best little space program of which you have never heard. If that is true for you, the reader, the book you are holding in your hand offers a bountiful education about the largely unwritten and quite commonly unknown piece of American space history, a history of contributions that range from open scientific discovery to deeply hidden successes, and some failures, in the national security space arena. More than that, this book offers fascinating insights into space development at a time, and in a place, where results were more important than bureaucratic processes, and when a leader’s worth was judged not by the modern standards of the media-smooth, politically-correct talking heads we too often see today at the helm of an enterprise, but by the technical respect in which he or she was held by those being led. At NRL, those old standards still apply. In a world of constant change, this is a trait that is more than worth preserving.

Mike Griffin

Under Secretary of Defense for Research and Engineering
(NASA Administrator 2005–2009)

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ACKNOWLEDGEMENTS

This book is the second I have written for the Naval Research Laboratory. The first one, *Pushing the Horizon*, was published in 1998 as part of the lab's celebration of its seventy-fifth anniversary.

The earlier book is an institutional history, a chronicle of a place that started small and focused on radio science and engineering in the 1920s and then became one of the country's great, broad-based research and development organizations. It is a place, with an overall mission founded in furthering the cause of national defense, which combines traits of major science and technology-driven universities like the Massachusetts Institute of Technology and top-tier corporate laboratories like DuPont's Experimental Station in Wilmington, Delaware, or the former and famous Bell Laboratories.

I never thought I would work on a massive project again for NRL, but in 2011 I was awarded a contract to write a book-length chronicle on the Naval Center for Space Technology, one of NRL's major organizational divisions. I had known about NCST and some of its accomplishments from my coverage of it in *Pushing the Horizon*, so I knew the project would be fantastically interesting.

Then I realized what I had gotten myself into. Within three years, I would have to discover through my reporting, interviewing, and research a narrative arc that would usher readers on an engaging tour of the origin, evolution, and significance of NCST's overall role in the Space Age, and of the scientists, engineers, and managers who have comprised the lab's adventure in space technology. It also was my personal hope that I would do so in a way that amounted to a welcome contribution to the scholarship in the areas of the history of the Space Age and the history of technology. I can only leave it to others to assess the degree to which I might have succeeded in these goals (the 2019 timing of publication is due, in part, to the extensive review process within NRL and the Department of Defense, as well as leadership shifts at both NCST and NRL).

What I must concede from the start is that this book, fat as it is, only captures a fraction of the many hundreds of people whose collective professional lives, over seventy years, sum into the life and times of the Naval Center for Space Technology. And even as the book chronicles only some of the scientists and engineers who have contributed to the life of NCST, it leaves yet more hidden the nontechnical personnel who contributed to the success of NCST with their essential management, admin-

istrative, and financial expertise and creativity. Without them, NCST surely would have been grounded. I thank Louise McDonald, one of those devoted and invaluable support staff, for her careful review of a draft of this book. To those living and dead who remain unmentioned, I apologize. My task was not to write a yearbook rife only with names and caption-length tidbits, but a long-form narrative that spans time and space and that hopefully would engage audiences even beyond those closely associated with the Naval Research Laboratory. As such, I strove to identify a series of projects, events, accomplishments and human players that all are like pixels which, when connected and arranged, reveal at least some worthy and informative picture of what a place like NCST has been about. I had to surrender to the reality that a place like NCST cannot be fully captured within the covers of a book.

I want to specially thank the late David van Keuren, a former NRL historian whose generosity and collaborative spirit helped me in my first NRL book project and, thereby, in this second book project as well. Without his partnership, I never would have been able to get my arms around the institutional, cultural, sociological, technological and other complexities of NRL as quickly I did.

I thank Art Collier whose patient devotion to the goal of producing a chronicle of NCST has kept me on track. His first-hand insight into how defense- and intelligence-related R&D plays out behind the scenes has helped me see sociocultural dynamics that I otherwise would have missed. He too has read more drafts of this book than I am sure he would have cared to. Chris Dwyer, head of NCST's Space Systems Development Department, has been my primary liaison within NCST and has been a welcome partner in figuring how to tell the NCST's story. His reviews and comments have helped to greatly improve the result and accuracy. Pete Wilhelm, director of NCST when it was established in that name in 1986, and a leader of NRL's space technology for decades before that, somehow managed to find time for multiple interviews and text reviews. He finally retired, after 56 years of service, at the very end of 2014. His power of recall and clarity of thought and expression are nothing short of amazing and have been a great asset to me. I thank also his successor, John Schaub, NCST's former director, for his patience and encouragement and for several invaluable discussions during the research phase of the book. I thank Lee Hammarstrom whose depth of knowledge of how NRL has operated in the larger context of the Navy, Department of Defense, and national leadership has been important and I am grateful for the partial draft of his own memoir that he shared with me. On that score, I am enormously grateful to James Winkler for sharing with me his memoir as a space technology engineer throughout some of NRL's and NCST's most golden years in the space technology business.

In the references and bibliography section, I have listed many other NRL and NCST scientists and engineers who I interviewed and who helped me with both the broad brushstrokes and the detailing of this narrative. Many of them generously read one or more drafts of chapters for which they had particular expertise or relevance.

I heap thanks upon the staff of Praxis Inc., the company that held the primary contract with NRL under which my subcontract for the book project was executed and managed. In that context, I thank in particular Jane Schaub, Kelly Davis, Kris Cheesebrew, and Sara Mateer. They have been a delight to work with. I thank Kathy Parrish, Claire Peachey, Jonna Atkinson, Gayle Fullerton, and the other publishing professionals at NRL who worked out the countless details that it takes to transform a raw, submitted manuscript into a hold-in-your-hand book, the kind I still like the most, even in an age of eBooks.

At home, where so much of the brooding, document shuffling, writing, rewriting, editing, and other tasks of writing a book unfolded, I thank my wife, Mary Amato, a prolific book author, for her relentless support. I also credit my sons, Simon and Max, for making me proud of them and for making me want them to be proud of my accomplishments, this book among them. Finally, I thank you, dear reader, for validating the entire effort.

INTRODUCTION

In the summer of 1923, on a bucolic plot of land along the Potomac River where it cuts southward through the bottom of the District of Columbia, a few of the 20 founding radio researchers of the newly opened Naval Research Laboratory already were craning their necks toward space. This first generation of NRLers, who commuted to the laboratory on dirt roads and by boat from Virginia just across the Potomac, could not have known it then, but their militarily significant interest in the upper atmosphere's effects on long-distance radio communication would set the lab on a path to becoming one the most consequential players in the gestation, birth, and maturation of the Space Age. From these personal and institutional roots in the 1940s and 1950s would emerge a culture of innovation that for the rest of the 20th century, and into the 21st, would lead to some of the highest of high technologies. Among these are space-based intelligence, surveillance, and reconnaissance (ISR) capabilities, the Global Positioning System (GPS) for planet-wide navigation and time synchronization (without which Internet and cell phone communication would be shadows of what they are), and battlefield technologies that sometimes played world-changing roles as they were deployed in the Cold War and in every phase of war and peace since.¹



It begins. In the summer of 1923, the Naval Research Laboratory opened for business along the east bank of the Potomac River in the southwest sector of Washington, DC. Building 1, the sole research building at the time, stood opposite a coal-fired power plant, a pattern shop, a foundry, and a machine shop, then the largest structure on campus. (NRL photo 23-060834(2))

NRL's status as a major and transformative participant in the still-unfolding history of the U.S. space program is little known by the general public. Ask most people on the street what constitutes the U.S. space program and they will quickly answer "NASA," referring to the National Aeronautics and Space Administration, which President Dwight D. Eisenhower signed into existence on July 29, 1958.² Some people might be aware that central to the original composition of NASA were the 8,000 employees, multiple research and test facilities, and \$100 million budget of the National Advisory Committee for Aeronautics, or NACA. However, unknown to most people is that much of the original expertise in rocket engineering and space science at what would become known as NASA's Goddard Space Flight Center in Greenbelt, Maryland, and much of NASA's original capabilities for managing entire operational satellite systems, resided in the presidentially mandated transfer of scientists, engineers, and technicians from the Naval Research Laboratory to the fledgling NASA and its multiple facilities.

NRL, first designated by the Department of the Navy during the lab's conceptual development as the Naval Experimental and Research Laboratory,³ got started in the rocket business when one of its leaders in guided-missile research and development in the 1940s, Ernst Krause, secured access for the lab to captured V-2 rockets that the Nazis had deployed as terror weapons in England and Belgium during World War II. These V-2 rockets could not loft anything into orbit, but they were the most powerful rockets in the world at the time. In addition to seeing their value for missile research, Krause, a Wisconsin farm boy turned physicist, knew the captured rockets offered a unique scientific opportunity for some of his NRL colleagues who had long coveted the possibility of making direct, in situ measurements of the upper atmosphere. With data from measurements like those, it was more likely that the NRL radio scientists would be able to tease out how ultraviolet radiation and X-rays from the sun affect the ionosphere at the edge of space and thereby the long-distance radio communication that was important to the Navy.⁴ In the years following the war, NRL's upper atmosphere researchers, with access to V-2s and with leadership positions on the multi-institution panel that decided how the nation's scientists and engineers could use the rockets, became among the most influential in the world in their field of upper atmosphere research.

With Krause opening the pathway to rocket-based science at NRL, which had world-class scientists and engineers on campus—among them Herbert Friedman, who would become a giant in the astronomy community; Jerome Karle and Herbert Hauptman, who in 1985 would share a Nobel Prize in chemistry for developing techniques for determining the specific arrangements of atoms in crystals; and Howard Lorenzen, who earned the moniker "Father of Electronic Warfare" for the innovations in electronic countermeasures that he and his colleagues provided the fleet during World War II—the lab became one of the earliest and most passionate adopters and then designers of rockets in the 1940s and 1950s.⁵ And once rockets entered the lab's portfolio

of tools and methods, they turned the heads of other creative scientists and engineers at the lab who envisioned how rockets for the first time could boost artificial satellites into orbit and how such orbiting platforms could perform many jobs for the Navy, Department of Defense, and the nation. Firing the imaginations of NRL's first generation of space technologists were wish-list possibilities that included communicating to far-flung vessels by bouncing radio signals off of satellites (including the original and natural satellite—the moon!); gathering intelligence and conducting surveillance and reconnaissance (on adversaries' anti-ballistic and air defense radar systems, for example); and navigating on land, on the seas, and in the air.⁶

This rocket-mindedness was ascendant at the lab in the years following World War II, so much so that the nation's leaders chose NRL in 1955 to execute Project Vanguard. This forward-looking national technology initiative proposed to launch into orbit, toward the end of the decade, the country's and perhaps the world's first artificial satellite, unless, that is, the Soviet Union's rocket engineers beat the United States to that prize. Project Vanguard was the nation's most audacious component of an already magnificently ambitious international science collaboration, known as the International Geophysical Year (IGY), in which researchers around the world would collectively study the planet's geophysical properties and behavior more comprehensively than had ever been done before.⁷

Like the United States, the Soviet Union also had publicly pledged to launch a satellite within the scientific context of IGY. And on October 4, 1957, Soviet engineers ended up beating the U.S. into orbit with their radio-beeping Sputnik 1. It was a humbling and, to many in the U.S., supremely threatening moment that might have been more endurable had Project Vanguard's attempt two months later to realize the nation's IGY promise to launch an instrument-bearing prototype satellite not resulted in a spectacular, televised, seen-by-all fireball of failure. It was widely derided with names like "flopnik" and "kaputnik." It was a dark episode for NRL's space pioneers.⁸

These were among the influences that led to the passing of the National Aeronautics and Space Act in the summer of 1958. Its central feature was the creation of a national civilian space agency, the National Aeronautics and Space Administration (NASA) and, with it, the near death of NRL's dozen-year exploration of rocket engineering and rocket-borne science. When NASA officially opened for business, some 200 NRL staff members from Project Vanguard were assigned by an Executive Order by President Eisenhower to become founding scientists, engineers, technicians, managers, and leaders at the brand new civilian space operation.⁹ Initially called the "Beltsville Space Center," the Maryland campus would become known as the Goddard Space Flight Center. This wholesale transfer of expertise would have spelled the end of NRL's advances into the Space Age had it not been for a handful of visionary space-minded engineers who remained at NRL—and some who applied to return to NRL from their transfer to the new NASA.

Among those who returned was Martin Votaw. He had worked on one of the world's first satellite-tracking systems, NRL's Minitrack system for Project Vanguard, and was adamant about the Navy's need to maintain its own expertise in the emerging Space Age. In 1959, Votaw became head of the small, newly formed Satellite Techniques Branch, and with his colleagues would begin to resurrect a space technology operation at NRL. At the end of that year, Votaw took one of the most important personnel actions of his career and, as it would turn out, for the U.S. space program: he hired a young engineer, Peter G. Wilhelm. Wilhelm would become a giant in the military space program and would become one of the longest continuously working engineers in the history of the U.S. space program. At the end of 2014, the 80-year-old Wilhelm had only just retired as the first and, until then, only director of the Naval Center for Space Technology, the Navy's premier in-house space engineering facility, headquartered at NRL.

To this Satellite Techniques Branch cadre, space was the vast ocean above in which the Navy and the nation would have to become present and capable, just as they were on the oceans below. This small group dedicated to keeping the Navy in space would emerge into a low-profile but high-impact component of the country's fledgling military space program. In time, this group (along with a few others at institutions such as the Johns Hopkins University Applied Physics Laboratory) would become for the Navy and national defense something like what NASA became for the high-profile civilian component of the space program. Over the next 50+ years, NRL's space technologists would conceive of, invent, develop, build, deploy, and operate at least 100 intelligence-gathering, surveillance, reconnaissance, navigational, communications, tactical, meteorological, scientific, and other kinds of payloads and satellites. These national assets have helped U.S. presidents, military and intelligence leaders, and even individual warfighters to counter uncertainty, ignorance, fear, and paranoia with data, information, and knowledge. The lab's central role in the creation of the Global Positioning System also connects its work to virtually every citizen in the U.S. and millions of others around the world who by way of their GPS-equipped navigation tools know where they are and where they are going.

Although the history of the last 60 years cannot be rewound and run again without these NRL-developed capabilities for comparison, it is defensible to claim that the lab contributed to the collective success of avoiding the dreaded alternate ending to the Cold War: mutually assured destruction by way of all-out nuclear war with the Soviet Union.

During those same years, NRL's low profile in the familiar NASA-centric narrative of the U.S. space program follows naturally from this reality: much of NRL's contribution to the country's space technology and capabilities has been classified at the highest levels. What may be said in general terms is that circling the globe in space as you read this sentence are what often are coyly referred to as "national technical means," a term that also includes ground-based command-and-control and

tracking stations profuse with massive antennas and geodesic radomes, the sophisticated computer analysis techniques that can pull out telling signals from the electromagnetic cacophony that fills the airwaves, and other associated technologies and facilities around the country and the world. (Drive along highways in, say, rural Maryland and Virginia, and you might just catch sight of some of the massive geodesic radomes of these ground stations.) At least portions of the stories behind some of these feats of technology, those whose operational lives ended in the 1960s and 1970s, now can be told publicly.

Among these stories are ones about NRL's roles in the arena of satellite-based intelligence gathering, reconnaissance, and surveillance. GRAB and Poppy, the code names of two of the nation's and world's first spy satellite programs during the Cold War, were top secret and unutterable in public until recent years.

It was evident from the start of the Space Age that satellites merely were the "orbiting peripherals" of what would become much larger and more complex global systems by which data from the satellites would become ever more useful to ever more end users. The NRL space technologists would have to develop expertise in designing and running ground stations for communicating with, controlling, and tracking satellites. They would have to invent and build a menagerie of electronic boxes for processing, encrypting, decrypting, interpreting, packaging, and distributing data for both strategic uses (such as mapping out enemy ability to track ballistic missiles) and tactical applications on the battlefield (such as determining a platoon's location in a featureless desert).¹⁰ And once others in the government, at national, state, and regional levels, began to see this range of capabilities the NRL space cadre had managed to realize, demand for tailored versions of these abilities grew from customers ranging from police departments to emergency response teams to the White House Communications Agency.¹¹



NCST Logo. The Naval Center for Space Technology logo features a generic satellite, but with details that pay homage to NRL's earliest satellites: the antenna-studded sphere resembles both Vanguard 1 and the satellite the public knew as SOLRAD 1 but that also housed a second, classified payload, GRAB 1.

It hasn't all been secrets for NRL's several generations of space technology engineers. Much of NRL's space technology program, which since 1986 has been subsumed within the NRL directorate known as the Naval Center for Space Technology (NCST), has been unclassified. This open work has many facets that reveal how NRL has been an integral partner with civilian, private, military, and other government efforts to push the envelope of space-based capabilities.

One of NRL's crowning and most visible achievements in this context is its seminal role in the creation of the Global Positioning System (GPS), which has expanded into civilian use beyond anyone's wildest prognostications in the 1960s when NRL and Air Force researchers began fleshing out GPS's conceptual foundations. Originally reserved for military uses ranging from missile targeting to ship navigation to location-finding for ground forces, and also for the equally important role of synchronizing the military's far-flung clocks, GPS has become a household acronym. It has become a contemporary wonder of technological innovation that many millions of people and countless industries have come to rely on. Whether you are a commander of a nuclear submarine in charge of an arsenal of sea-launched missiles, a dad in search of a soccer field in the Bay Area of California, or a teenager with a smart phone bent on locating the closest source of pizza in Worcester, Massachusetts, GPS now has become part of routine life. It has transformed how ordinary citizens navigate from a billion Point A's to a billion Point B's.

Less visible but just as critical is the system's capability in relaying "time synchronization" signals from a master clock (maintained at the U.S. Naval Observatory in Washington, DC) to millions of internal clocks in computers, cell phone towers, electric grid components, receivers, transmitters, and other devices in our increasingly high-tech systems. Without such precise synchronization, these devices and systems would be unable to, among other things, communicate with each other, tease apart multiple signals from a mix of signals, keep electrical current flowing stably through the grid, or make targeting calculations.¹² The GPS is just one of the more visible life-changing technological systems with NRL's mark all over it that this book chronicles.

Another high point for the lab was its leading role in the ambitious 1990s project known by most as Clementine but also more formally as the Deep Space Program Science Experiment (DSPSE). Originated by NASA and the Department of Defense as a joint mission to demonstrate the capability for low-cost, high-value space exploration, the project integrated small, lightweight, and remarkably capable sensors, imaging technologies, and navigation, propulsion, and other components and systems into a smaller, "smarter" satellite. Administration and funding fell under the wing of the Strategic Defense Initiative Organization (SDIO), known later as the Ballistic Missile Defense Organization (BMDO) and now the Missile Defense Agency (MDA).¹³

Just 22 months after NRL was tasked with leading the multi-agency effort, a Titan II booster lofted Clementine toward its first destination, the moon, where it would map the lunar surface more thoroughly than ever before and from which it was to set off for its second destination, the near-Earth asteroid Geographos. In both cases, the spacecraft was to demonstrate that it could hone in on, mostly autonomously, an object in space and then observe and record it in great detail. Clementine succeeded spectacularly with its moon rendezvous, during which it amassed 1.8 million images that amounted to, at the end, the finest visual mapping of Planet Earth's one and

only natural satellite. Disappointingly, a software error crippled the spacecraft before it could make it to Geographos. Even so, President Bill Clinton publicly lauded the accomplishment. Said Clinton, “The relatively inexpensive, rapidly built spacecraft constituted a major revolution in spacecraft management and design.”¹⁴

A few years later, the aftermath of the terrorist attacks of September 11, 2001, would find expression in NCST’s research and development portfolio. As the attacks starkly demonstrated how the world’s security threats were shifting from primarily nation states to include also nationless terrorist organizations, the lab redoubled its efforts to leverage the space-based technologies it had helped develop over the years into ones that could serve in the emerging “homeland security” context. C4ISR is the acronym that applies here: Command, Control, Computers, Communications, Intelligence, Surveillance, and Reconnaissance. One major embodiment of NRL’s work in this arena falls under the rubric of “maritime domain awareness” for keeping a watch on thousands upon thousands of vessels on the world’s oceans. This has meant fusing many types of intelligence, surveillance, and reconnaissance data, along with secure communications systems, into a versatile C4ISR framework that can be tailored for a diversity of threats, such as terrorists trying to deliver weapons of mass destruction to American ports, and a diversity of end users, such as emergency response teams dealing with in- frastructures wrecked by hurricanes and other natural or human-made disasters, and police forces ensuring safety and security at iconic national and international events like the Super Bowl or Olympics.

NRL was founded several years after Thomas Edison suggested in 1915 to the Secretary of the Navy, Josephus Daniels (whose ban on liquor and encouragement of coffee on Naval vessels during the prohibition brought us the phrase “Cup of Joe”), that the Navy needed its own invention factory. When the lab opened its doors in 1923, it was destined to evolve into the Navy’s version of the corporate laboratory, akin to Edison’s own “invention factory” in Menlo Park, New Jersey, Corning’s glass research and development facility in upstate New York (Sullivan Park), and DuPont’s Experimental Station in Wilmington, Delaware. NRL’s mission in life would be to apply new scientific knowledge and engineering know-how to develop more capable technologies that are useful to the Navy.¹⁵ In time, its clientele would expand beyond the Navy to the rest of the Department of Defense and then to the entire citizenry of the country.

From its original contingent of radio scientists and engineers, NRL has grown into an R&D campus with scores of buildings at several location and more than 2,200 scientists, engineers, technicians, and support personnel working on an annual R&D budget in recent years of about \$1 billion. It operates under a Working Capital Fund model, which means its researchers only work and get paid if they can offer scientific or technology development projects that others want and are willing to pay for. Without these paying customers, mostly in other parts of the government, NRL would all but shut down. About half of the technical staff are physicists and engineers and



The NRL Campus. In its more than 90 years, NRL has evolved into a large R&D campus with some 100 buildings and nearly 2,500 full-time employees, more than half of which hold master's or doctoral degrees. The largest, hangar-like structure, Building A59, is the primary home of the Naval Center for Space Technology. (NRL photo 160217-N-JF840-068)

the other half have expertise in chemistry, materials science, acoustics, ocean science, astronomy, astrophysics, mathematics, computer science, robotics, electronic warfare, sensor systems, systems engineering, and dozens of other areas. This unique diversity within the Department of Defense's research and development infrastructure is what has allowed NRL as a whole, and the Naval Center for Space Technology in particular, to develop a successful track record in solving inherently multidisciplinary technology challenges. Behind the scenes but just as essential were those carrying out the administrative and logistical tasks that come with developing new space technology. Establishing and manning international field sites to monitor and perform command and control functions of spacecraft during orbit, for example, demanded creativity and skills sets in areas such as real estate, financial tracking, security operations, and contracts and procurements.

Even as it resides within this diversity, NCST itself has evolved into one of the world's more technically diversified workforces with access to one of the world's more fully equipped sets of space technology and satellite operation facilities. Between its two divisions—the Space Systems Development Department (SSDD, Code 8100) and the Spacecraft Engineering Department (SED, Code 8200)—NCST's some 250 scientists, engineers, technicians, and support personnel collectively supply just about every type of expertise needed to usher spacecraft from their conceptual cradles, onward through

development, assembly, testing, launch, and operation phases, all the way to the end of their service lifetimes.¹⁶ NCST maintains a close partnership with industry throughout these stages, as the following chapters will show.

NCST has just about all the facilities and equipment that it takes for this rich bastion of human talent to build, assemble, test, and otherwise prepare spacecraft for launch. A partial list of such facilities includes voluminous “high bays” for satellite fabrication and assembly; the “Big Blue” thermal vacuum chamber for subjecting entire spacecraft to simulations of extreme space environments; a launch-simulating acoustic reverberation chamber; RF (radio frequency) anechoic chambers for testing antenna behavior; an electromagnetic interference and compatibility (EMI/EMC) chamber for testing how a spacecraft’s myriad electronic and RF components interact; spin tables for characterizing the balance and behavior of spacecraft in orbit; clean rooms for fabricating specialty microelectronic chips and other high-precision and sensitive components; an atomic clock testing and characterization facility; a fuel testing facility; leading-edge integration and testing facilities for electronic, RF, and optical components and systems; computer-aided design and manufacturing (CAD/CAM) capacity; and tools and algorithms for determining, tracking, and analyzing orbital trajectories, known more technically as ephemerides. And once NCST’s payloads are in orbit—and increasingly also the payloads built by others—the Center also has the right human stuff and technology to operate and manage them at NCST’s telemetry, tracking, control, and communications stations at Blossom Point, Maryland (one of the world’s first satellite ground stations), the Midway Research Center in Stafford, Virginia, and elsewhere.¹⁷

With a mission to prepare for the Navy’s and nation’s imminent and future needs in space, NCST’s research and development portfolio spans an astonishingly wide spectrum. A very partial listing of NCST’s scores of research areas includes systems engineering, satellite mission analysis and simulation, stem-to-stern space and aircraft payload design and implementation, laser-based satellite ranging and communication, advanced data management, orbital dynamics, autonomous navigation, interplanetary navigation, communications theory and systems, ground station engineering, tactical communications systems, antenna design, precision navigation and timing technology, precision tracking and ranging, all aspects of satellite design, testing, and fabrication, propulsion systems, machine vision, hydraulics and pneumatics control ... the list goes on and on. It is what has given NCST the confidence to sometimes associate its own sense of self with the Star Trek–inspired slogan visible on some of NCST’s walls: “To Boldly Fly What Has Never Been Flown Before.”¹⁸

¹ See, for example, Ivan Amato, *Pushing the Horizon: Seventy-Five Years of High Stakes Research and Technology at the Naval Research Laboratory* (Washington, DC: Naval Research Laboratory, 1998); Herbert Gimpel, “History of NRL,” two volumes (first 50 years), unpublished, 1975; Bruce Hevly, *Basic Research Within a Military Context: The Naval Research Laboratory and the*

Foundations of Extreme Ultraviolet and X-ray Astronomy, 1923–1960 (Baltimore, MD: Johns Hopkins University, 1987).

² “National Aeronautics and Space Act of 1958,” Public Law 85-568, 72 Stat. 426. Signed by the President on July 29, 1958.

³ Annual Report of the Department of the Navy for the Fiscal Year of 1920, 1921 (Washington, DC: Government Printing Office, 1921), pp. 64–65.

⁴ Louis A. Gebhard, *Evolution of Naval Radio-Electronics and Contributions of the Naval Research Laboratory*, NRL Report 8300 (Washington, DC: Naval Research Laboratory, 1979), p. 303.

⁵ Herbert Friedman, “From the Challenges of World War II to the Frontier of Space,” in *1992 NRL Review* (Washington, DC: Naval Research Laboratory, 1992).

⁶ NRL Report 5097, “A Satellite and Space Vehicle Program for the Next Steps Beyond the Present Vanguard Program,” December 10, 1957.

⁷ See, for example, Constance Green and Milton Lomask, *Vanguard: A History* (Washington, DC: National Aeronautics and Space Administration, 1970).

⁸ Hugh Sidey, “The Man Who Took the Beating for Vanguard,” *Life Magazine*, March 31, 1958, p. 35.

⁹ See, for example, Lane E. Wallace, *Dreams, Hopes, Realities: NASA’s Goddard Space Flight Center, The First Forty Years* (Washington, DC: National Aeronautics and Space Administration, 1999), pp. 18–19; Green and Lomask, *Vanguard*.

¹⁰ Robert Eisenhower, interview with author, March 12, 2012.

¹¹ Robert Richard, George Arnold, and Bruce Morgan, in joint interview with author, April 19, 2012.

¹² Ivan Amato, “Why, in the Jurassic Era, an Earth Day May Have Been Only 23 Hours Long,” *Washington Post*, September 23, 2013.

¹³ *A Clementine Collection* (NRL/PU/1230-94-261) (Washington, DC: Naval Research Laboratory, June 1994, reprinted March 1999). President Ronald Reagan announced the Strategic Defense Initiative (SDI), which came under the auspices of the SDI Organization (SDIO). A decade later, in 1994, the Secretary of Defense renamed SDIO as the Ballistic Missile Defense Organization (BMDO) and in 2002 the organization underwent another name change to the Missile Defense Agency (MDA).

¹⁴ William J. Clinton, “Report on Aeronautics and Space for Fiscal Year 1994,” Congressional Record (Senate), p. S7388, May 24, 1995.

¹⁵ See Amato, *Pushing the Horizon*, p. 14.

¹⁶ On the to-do list for NCST, as it is for just about any organization that builds and operates satellites, is to figure how to manage, recycle, reposition, and otherwise manage dead and orbiting spacecraft. The massive and growing population of space debris already poses hazards for operating in space and the problem will only get worse unless innovators at NCST and elsewhere come up with solutions.

¹⁷ For information on NCST’s facilities and research programs, see these Naval Research Laboratory corporate publications, available at <http://www.nrl.navy.mil/media/publications>: *NRL Major Facilities* (online only); *NRL Fact Book* (information on NRL’s structure, personnel, and programs, printed every other year); and *NRL Review* (collection of research articles from all research divisions, published annually).

¹⁸ This slogan appears sometimes on posters and other media that end up in, among other places, NRL meeting rooms and PowerPoint presentations.

1

MINDING THE SKY

With its establishment in 1923, the Naval Research Laboratory became “the Navy’s sole in-house organization with full responsibility for advancing the Navy’s radio capability,” noted radio engineer Dr. Louis Gebhard. A devotee of wireless transmission technology¹ since his high school days early in the century, Gebhard would work at NRL for more than 40 years and become one of its most spaceward-looking leaders.² It was this pursuit of improvements in one of the Navy’s most basic technology categories, communications, which inexorably required NRL radio experts to ask questions about the upper atmosphere’s effects on long-range radio communication. It was the scientific challenge of answering those questions about the upper reaches of the sky that would turn NRL into a spawning ground of the Space Age.

The first director of NRL’s Radio Division was Dr. Albert Hoyt Taylor, a Chicago-born, pipe-smoking physics professor who joined the Naval Reserve prior to World War I, attained the rank of lieutenant, and became officer-in-charge at the Great Lakes Naval Radio Station after the Great War began. He was promoted to the rank of Commander in 1918. As ground was breaking in 1920 for construction of NRL’s first buildings, Taylor was the Navy’s top radio scientist and a natural choice for director of the lab’s Radio Division. The lab’s only other division in 1923 was the Sound Division, then staffed by a handful of researchers focused on the science and



Radio Men. Dr. A. Hoyt Taylor (left), shown here in a World War II era photograph, was the Navy’s top radio scientist when he assumed leadership of the Naval Research Laboratory’s Radio Division in 1923. Dr. Louis Gebhard (right), shown here in 1954 when he was in charge of NRL’s Radio Division II, was one of the first at the lab to envision using rockets to study the upper atmosphere’s effects on radio communication. (NRL photos 60834(H-602) and 60834(H-555A))

technology underlying the detection of submarines. Until 1949, when the lab reorganized to have a civilian director of research, the head of the lab was a military man, the first one being Rear Admiral William S. Smith.

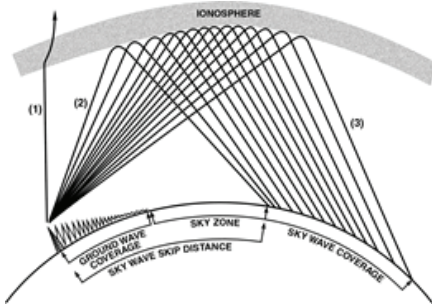
At a time when most radio technology was based on long-wavelength, low-frequency signals, Taylor was betting that short-wavelength, high-frequency signals would be a major trait of future naval radio technologies, and not just for communication. One pragmatic reason Taylor was leaning toward developing capabilities with high frequencies was that the public broadcasting stations at the time had been encroaching on the low to mid frequencies—from 550 kilohertz (550 thousand waves per second) to 1.5 megahertz (1.5 million waves per second)—that the Navy had been using. This encroachment was extensive enough that, in the words of Gebhard, “Considerable political pressure was brought to bear upon the Navy to relinquish its use of this band.”³ That swath of frequencies became known as the “radio-broadcast band.”⁴ One potential military perk of developing communications techniques at higher frequencies, which generally refers to those frequencies between a few megahertz and 30 megahertz, was that the energy these signals carries tends to be absorbed by the atmosphere more so than is the case for lower-frequency signals. Particularly with a low-power transmitter, it would be harder for an adversary to eavesdrop on these signals from far away, and that made them attractive for secure ship-to-ship communication channels. But it also meant that systems using high frequencies needed to be more sensitive to weak signals and have more capable amplification circuitry.

“Although we did not see the tremendous possibilities [beyond expected gains in areas such as ship-to-ship communications] for the use of high frequencies in the field of naval communications, we did see that they would be extremely valuable provided we could sufficiently stabilize transmitters and receivers to make use of such frequencies practical under naval conditions,” Taylor stated later.⁵ This was engineering research and development, through and through. But it also was, in a sense, out of reach. The behavior of high-frequency radio waves is intimately connected to properties and phenomena at the edge of space, and thereby, to the sun and the energy it sends Earthward. In the 1920s, there was no way to directly observe and measure what was going on scores of miles overhead.

Radio operators around the world had become well aware of a seeming paradox about high-frequency signals: the signals could be transmitted over astoundingly far distances, many thousands of miles. This was a big part of radio’s “magic.” The radio community also knew that there seemed to be patterns to the long-distance transmissions. But the patterns were quirky, often wildly so. A key clue to the physics behind the transmission would come from observations that the signals were receivable at specific distances, called skip distances, from the transmitter. No one quite knew how this was working, but for Navy commanders coveting the seemingly impossible ability to communicate with their far-flung ships on the world’s seas, the prospect of reliable long-distance radio communication—at the speed of light, no less, and without re-

quiring the outlandish and impractical task of tapping into undersea telegraph cables while at sea—was alluring indeed.

The leading theory for the skip distance phenomenon was spelled out in mathematical detail in 1924 by British scientist Sir Joseph Larmor,⁶ who proposed that the upper atmosphere included a layer of electrically charged atoms, or ions, which behaved like a spherical radio mirror enveloping the planet. This layer—itsself comprising several discernible layers, each of which reflects radio waves—became known as the ionosphere.



Skip Distance. Navy radio researchers were both vexed and intrigued by the ability of high-frequency radio waves to be received at specific locations thousands of miles away from a transmitter. Physicists at NRL and elsewhere uncovered how layers of the ionosphere, in the far upper atmosphere, acted like mirrors for radio waves, causing the waves to ricochet between the ionosphere and Earth, thereby bending signals around the curvature of the Earth. (Army Training Document, <https://rdl.train.army.mil/catalog/view/100.ATSC/8594DF18-D94D-432C-823B-7D40C4B4BE4A-1274317197310/9-64/chap2.htm>)

With the Earth's surface having a similar radio mirror effect, a high-frequency radio signal could begin at a transmitter in, say, Washington, DC, and then ricochet between the ionosphere and the surface multiple times as the signal bent around the Earth's curvature toward distant receivers. When Taylor's radio colleague Leo Young, who previously had worked with Taylor at the Great Lakes Naval Radio Station, demonstrated that a 50-watt, high-frequency transmitter at NRL could communicate more reliably with Navy facilities in Balboa, along the Panama Canal, than could a massive 250,000-watt transmitter of long-wavelength signals, the Navy's Communication Service was won over.⁷ This was akin to seeing a dim light bulb thousands of miles away.

In early experiments using a transmitter designed to emit particularly high frequency signals with unprecedented stability—an important feature when using radio wavelengths like rulers for measuring distances—Young and Gebhard determined that the height and thickness of the ionosphere varied during the day, across seasons, and in different locations on the planet. These variations appeared to be confined within an altitude range of 55 to 130 miles.⁸ The higher the ionosphere, the farther the ricochet distance for a radio signal.

Although the NRL researchers could determine some of the ionosphere's most basic geometric characteristics with their remote radio probing, this upper part of the atmosphere was literally unreachable for any direct measurements of, say, its chemical composition or the density of electric charges. Yet the NRL radio researchers knew they needed just those kinds of measurements to understand the ionosphere enough so they could transform the hit-or-miss aspect of ionosphere-mediated radio

communication into a set of guidelines the Navy could use to render its high-frequency communication more predictable and reliable.

In lieu of a full understanding about how the ionosphere affected radio transmission, and still with no means to make direct measurements of the ionosphere, Taylor turned to the world's postal system to map out propagation patterns, in particular those skip distances that corresponded to the ricochet points of the radio waves. "Taylor and other amateurs were discovering skip distances just by calling in the dark and seeing who answered," recounted Dr. Edward O. Hulburt, who joined NRL in 1924 to run the newly established Heat and Light Division. "He'd say, 'Stand by, boys, I'm working tomorrow night on three meter [radio] waves. What do you hear? Send me postcards.'" This network of amateurs and the postcard campaign revealed that the average skip distance increased as the wavelength of the radio signal decreased. For wavelengths of 16, 21, 32, and 40 meters (corresponding to high frequencies in the tens of megahertz range), for example, the skip distances were 1,300, 700, 400, and 175 miles, respectively. With this data, and a model of the ionosphere as a sea of free electrons whose population and thickness at different parts of the world depended on the amount of solar energy impinging on it, the NRL radio team was moving toward a science-to-technology payoff. The picture of the ionosphere that was emerging was that of a radio mirror whose position in the sky could rise or fall in different places around the world depending on the solar energy flux.



Ionosphere Science. When Dr. Edward O. Hulburt came to NRL in its first years in the 1920s, he added his expertise in optical physics to the study of radio behavior, opening a pathway to understanding how the ionosphere affects the propagation of radio signals. (NRL photo Hulburt(H))

The Navy's commitment to high frequencies meant that the NRL radio wizards, along with scientific colleagues who also were investigating the electrical and magnetic features of the atmosphere, would have to obtain a much more detailed understanding of long-distance radio propagation. And this meant they would need to observe, measure, probe, and otherwise examine the ionosphere, a region of the

atmosphere that began above the stratosphere and went all the way to that poorly defined height where the sky ends and space begins. It was a place where no person, balloon, or any other human-made object had ever been. Since it was not possible to study it directly, it would take unprecedented ingenuity to gather enough data to understand it via indirect means.

There was something else that was curious to Taylor about high-frequency radio signals, something that eventually would set the lab's innovators on a trajectory even above the ionosphere. In 1922, while at the nearby Anacostia Aircraft Radio Laboratory awaiting the official opening of NRL, Taylor and Young had made a discovery—one that would have enormous consequences—during their surveys of radio transmission and reception along the Potomac River. In particular, they were puzzled one day by a series of signal fluctuations. Then they realized what they were witnessing: reflections of radio signals from a wooden steamer, the *Dorchester*, sailing by on the river.¹⁰

This was one of the world's first glimpses of the type of electromagnetic behavior underlying "radio detection and ranging," or radar, for short. It would be a fateful observation that led to the birth of naval radar in the 1930s and 1940s and to the development of a range of enormously important radio-based technologies in World War II and ever since. It was not lost on Taylor that high frequencies were what would make this phenomenon valuable to the Navy; low frequencies had wavelengths hundreds of meters long, too large to rely upon for locating most ship-sized objects precisely enough. Using wavelengths longer than the object to be detected would be akin to trying to sift grains of rice using a screen with a one-inch mesh. NRL's initial discoveries in radar would open its engineers' imaginations over subsequent years in magnificent ways. Historians of technology would come to rate the invention and development of radar at NRL, at MIT's "Rad Lab," and in England as one of the most important of the 20th century.¹¹

Radar R&D would become one of NRL's greatest strengths. Included in NRL's research portfolio were technologies for detecting, characterizing, and jamming the radar systems of adversaries. Along these lines, during the height of the Cold War in 1960, NRL space technology pioneers, particularly Howard Lorenzen, Martin Votaw, and Reid Mayo, would launch the world's first intelligence-gathering payload into orbit. Known by the then-classified designator Dyno 1 (and more widely by its cover name GRAB, for Galactic Radiation Background experiment), the Cold War payload listened in on and helped characterize Soviet anti-aircraft and anti-ballistic-missile radar.

The story of the first spy payload and its more capable follow-on versions would only begin coming out to the public, at least in parts, in 1998, on the occasion of the 75th anniversary of NRL, and then again in 2005.¹² But the original incentive to reach higher up in the sky than humanity ever had gone before was in place at NRL from its beginning by virtue of the militarily relevant challenge of pushing radio communication into high frequencies. Another step toward an era of space science and technol-

ogy would unfold in those early years by way of the forward-looking mindset of E.O. Hulburt, whose fundamental studies with Taylor into the propagation of electromagnetic radiation, whether in the form of visible light or invisible radio signals, would help put NRL onto the scientific map.

¹ Bruce Hevly, *Basic Research Within a Military Context: The Naval Research Laboratory and the Foundations of Extreme Ultraviolet and X-ray Astronomy, 1923–1960* (Baltimore, MD: Johns Hopkins University, 1987), p. 21.

² Louis A. Gebhard, *Evolution of Naval Radio-Electronics and Contributions of the Naval Research Laboratory*, NRL Report 8300 (Washington, DC: Naval Research Laboratory, 1979).

³ Gebhard, *Evolution of Naval Radio-Electronics*, p. 44; Susan J. Douglas, *Inventing American Broadcasting 1899–1922* (Baltimore, MD: Johns Hopkins University Press, 1987).

⁴ Gebhard, *Evolution of Naval Radio-Electronics*, p. 44.

⁵ A. Hoyt Taylor, *The First Twenty Five Years of NRL* (Washington, DC: Navy Department, 1948), p. 17.

⁶ Sir Joseph Larmor, “Why Wireless Electric Rays Can Bend Around the Earth,” *The London, Edinburgh and Dublin Philosophical Magazine and Journal of Science* 48 (1924): 1025–1036; A.H. Taylor and E.O. Hulburt, “The Propagation of Radio Waves Over the Earth,” *Physical Review* 27, no. 2 (February 1926): 189–215.

⁷ Taylor, *The First Twenty Five Years*, p. 17.

⁸ G. Breit and M.A. Tuve, “A Test of the Existence of the Conducting Layer,” *Physical Review* 28 (1926): 554–575. See also Tuve and Breit, “Note on a Radio Method of Estimating the Height of the Conducting Layer,” *Terrestrial Magnetism and Atmospheric Electricity* 30 (1925): 15–16; Hevly, *Basic Research*, pp. 31–32.

⁹ Edward O. Hulburt, oral history, NRL History Office.

¹⁰ David Kite Allison, *New Eye for the Navy: The Origin of Radar at the Naval Research Laboratory*, NRL Report 8466 (Washington, DC: Naval Research Laboratory, 1981), pp. 39–40.

¹¹ See Robert Buder, *The Invention that Changed the World: The Story of Radar from War to Peace* (New York: Simon & Schuster, 1996).

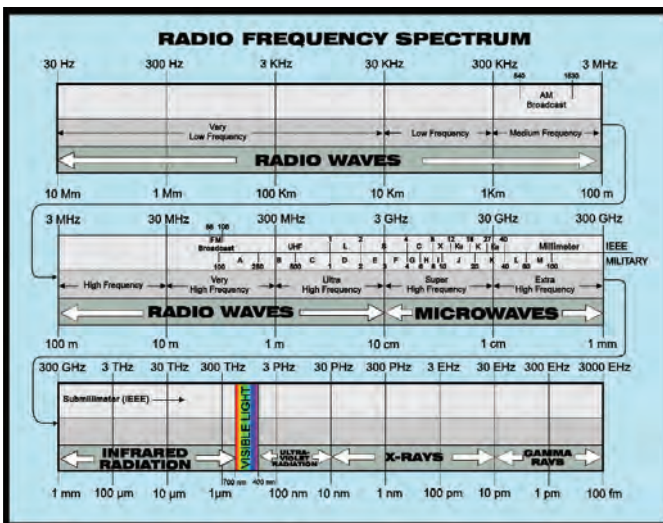
¹² Robert A. McDonald and Sharon K. Moreno, *Raising the Periscope...Grab and Poppy: America's Early ELINT Satellites* (Chantilly, VA: National Reconnaissance Office, 2005).

2

A ROCKET STATE OF MIND

Catalyzing great discoveries through interdisciplinary mixing of minds, concepts, and methodologies was a hot topic of discussion in late 20th century university culture. At NRL, this culture had begun taking hold far earlier. Dr. Edward O. Hulburt, one of the lab's early hires, received his Ph.D. from Johns Hopkins University in optical physics. But he knew of radio too. During World War I, Hulburt worked in an Army Radio Signal Corps workshop in Paris's Latin Quarter where he and his coworkers built radio sets, delivered them to the troops on the front lines, and then quickly worked on the next improved generation of radio sets based on feedback from the front.¹

As an optics expert, radio waves were to Hulburt just longer-wavelength versions of the infrared, visible, and ultraviolet light he was more accustomed to studying. Light and radio—both were just different embodiments of electromagnetic radiation. Graphical depictions of the electromagnetic spectrum typically line up long-wavelength microwave and radio waves to the left of infrared, visible, and ultraviolet wavelengths, which line up to the left of shorter wavelength portions of the spectrum, including X-rays and gamma rays.



The Electromagnetic Spectrum. When viewed together on an electromagnetic spectrum, the common physics underlying X-rays, light, and radio becomes apparent.

Hulburt and A. Hoyt Taylor, superintendent of the lab's Radio Division, combined their respective knowledge regarding the reflection and propagation properties of electromagnetic radiation and the particular traits of radio waves. In 1926, in the journal *Physical Review*, they published what became a hugely influential paper in which they laid out a general mathematical model to account for how the ionosphere affected the propagation behavior of radio waves.² The paper described the mechanism by which radio frequencies from 100 kilohertz (kHz) to 20 megahertz (MHz) (corresponding to low-frequency wavelengths of about 3000 meters to modestly high-frequency ones with wavelengths of about 15 meters) were reflected by and through a medium of heavy ions and electrons, which presumably was what the ionosphere was like. Their theory adequately explained the skip-distance effect and agreed with experimental data at distances up to 16,000 kilometers from the transmitter, or about two-fifths the distance around the world.³

This paper would become NRL's most prominent early contribution to the scientific literature. It simultaneously furthered basic understanding of the ionosphere and provided guidance to the Navy for how and when to choose specific frequencies for high-frequency communication. Almost 70 years later, the American Institute of Physics would include this paper among the most seminal papers published in the seminal journal *Physical Review* in all of the 20th century.⁴ This was a paper in which theory and math matched empirical, on-the-ground observations by radio operators around the world who recorded when and where they were able to receive high-frequency signals from transmitters run by NRL's Radio Division. Still lacking, however, was the deeper scientific foundation of how the ionosphere behaved and affected radio signals, and this could only be constructed from actual measurements of the electrons and ions in the ionosphere at different times of the day and year.

Direct measurements of that sort indeed were on the wish lists of upper atmosphere researchers at NRL and elsewhere. Hulburt, for one, was well connected with Dr. Merle Tuve and Dr. Gregory Breit, both young ionosphere researchers at the nearby Department of Terrestrial Magnetism (DTM) of the Carnegie Institution of Washington (CIW) located in a bucolic, forested section of Washington, DC. They too wanted to study the ionosphere in its own lofty venue and Hulburt would join them in attempts to drum up political and financial support to move forward on their audacious desires. Hulbert first got to know Tuve at Johns Hopkins University where Hulbert taught Tuve, who was a graduate student there. Tuve continued his connection with Hulburt at NRL in 1925 where he secured access to a powerful set of radio transmitters at an NRL-run radio station known as KDF for probing the upper atmosphere with radio signals.⁵ Tuve would later run Johns Hopkins University's Applied Physics Laboratory (APL), which was established as part of the country's technology development effort during World War II, and thereafter would become both a sometime partner and sometime rival of NRL in space technology development.

Of all scientific specialists, those interested in the upper atmosphere were the ones most tuned in to any development that might bring them physically closer to their favorite object of study. Word of one such development began circulating in 1926. On March 26 of that year, Robert Goddard, a rocket visionary since his high school days, launched his first liquid-fueled rocket in Auburn, Massachusetts. Its engine fired for about 2.5 seconds, enough to loft the rocket 41 feet and send it half a football field from the launch point.⁶

To be sure, it was a modest accomplishment for what Hulburt, Tuve, and Breit had in mind; what they needed was a rocket that could travel straight up to the ionosphere, which was more than 50 miles above their heads. Goddard's own vision for rockets in fact went way beyond the ionosphere. In late 1919, for example, the Smithsonian Institution published his essay titled "A Method for Reaching Extreme Altitudes."⁷ In it, he mused about building a rocket charged with "flash powder" that could reach the moon, at which time the powder would ignite spectacularly on impact so that the feat would be visible to observers on Earth.

Even earlier, Russian rocket visionary Konstantin Tsiolkovsky wrote of "reactive devices," something like rocket engines, for launching artificial satellites. Beyond that, he imagined building orbiting space platforms as way stations for interplanetary flight.⁸ German rocket visionary Hermann Oberth followed suit in the 1920s when he published his machinations of using rockets for planetary exploration.⁹ So by the late 1920s, rocket visionaries in the United States, Germany, and the Soviet Union all had strongly registered in writing their inclinations to build vehicles for reaching space. And Goddard had taken some of the first concrete steps to do so. It would be these same three countries over the next few decades whose space-bound ambitions would compete and clash while driving one another to achieve technological feats that stand out as among humanity's most consequential accomplishments, for better and for worse.

Hulburt would be the most influential early carrier of rocket visions into NRL. Goddard's rockets particularly grabbed him. Despite their modest abilities, Hulburt took them to signify that any scientific imaginings about shuttling instruments all the way to the heights of the ionospheric radio mirror were not just pipe dreams. And Hulburt didn't waste time to try to move that feeling onward and upward.

In a letter dated June 17, 1927, to Dr. John A. Anderson of the Carnegie Institution of Washington's Mt. Wilson Observatory in California, Hulburt, along with Tuve and Breit of DTM, described their efforts to generate support for the high-altitude research direction that Goddard's little rockets so vividly suggested to them. Anderson recently had been in Washington, DC, for a scientific conference, where he spoke about his institution's support of Goddard's rocketry work. The three scientists wrote to Anderson, "After your visit in Washington at the time of the April meeting of the Physical Society, we have been very much interested in the rocket for the purpose

of exploring the upper atmosphere.” Hulbert noted that the military commander of NRL, Captain Edgar G. Oberlin, was talking up the idea within Navy circles. Colleagues of Breit and Tuve at the DTM’s Geophysical Laboratory had looked into collaboration with the Army. The letter writers also noted that they would consider approaching “some wealthy people” if they could learn more details of Goddard’s rockets.¹⁰

Practical rocket technology for upper atmosphere research, let alone for placing satellites into orbit, was still decades away. But the discussion about rockets, once begun in this circle, would continue at the lab, historian Dr. Bruce Hevly observed in his Ph.D. dissertation in which he analyzed the emergence of upper atmosphere research at NRL. In 1929, for one, Dr. John Fleming, then acting director of CIW’s DTM, wrote to Hulbert, asking him how he would put a rocket to use. In his reply, Hulbert proposed, in Hevly’s words, “that rockets would be useful in an intermediate region from 30 to 70 kilometers, between regions understood from balloon-borne instruments and those examined using radio waves. He recommended instruments to collect air samples, measure temperature, detect various atmospheric gases, and measure the action of the winds and the propagation of sound. Special photographic plates could be prepared to measure X-rays and ultraviolet light.”¹¹

Cognizant of where his paycheck was coming from, Hulbert crafted the letter to Fleming so that it stressed the possibility that rockets could become a cheaper means than, say, enormous long-range guns, for delivering destructive and lethal ordnance to the enemy over long distances. The letter’s less violent ulterior motive was not camouflaged: it made it clear that a secondary use of the same technology could be to ferry scientific measuring payloads to higher locations of the planet than had ever been reached before. Rockets could push forward the scientific understanding of the ionosphere and thereby could improve high-frequency radio communication for the Navy, the letter said. Noted Hulbert, for clarity, “The behavior of the projectile might yield information of interest to certain departments of the Army and the Navy.”¹²

Goddard’s modest accomplishment in 1926 and in the years that followed may have catalyzed a hunger for rockets in Hulbert and thereby at NRL. But it could be little more than a hunger pang for 20 years, at which time another giant of NRL’s history, Dr. Ernst Krause, would secure the means—in the form of the V-2 rockets that the Nazis had used as a terror weapon during World War II—by which NRL’s scientists and engineers (and their colleagues in upper atmosphere research at other institutions) could get a taste of what rocket technology would enable them to do. Krause, a self-supporting graduate student in physics in 1938 at the University of Wisconsin in Madison, got his first job at NRL when the lab was still more known for its engineering than for its science. Taylor wanted to beef up NRL’s radio research and development work with some fundamental scientific expertise and he went in search of the same at UW Madison, where he himself had taught several decades earlier.¹³

“Much of the work at the Laboratory at that point was being done in the field of radio, and they had people who were ex-radio operators in the Navy, and some hams,” Krause recalled later, referring to radio hobbyists who amounted to one-person radio stations working out of basements, sheds, and garages. Taylor, he said, “wanted to inject more physics into the Laboratory’s activities.”¹⁴ Taylor, who had earned his own Ph.D. at the University of Göttingen in Germany in 1909,¹⁵ checked in with the physics department at the familiar-to-him University of Wisconsin for top-notch students who might help the Navy push radio-based technology further in the interest of national defense.¹⁶

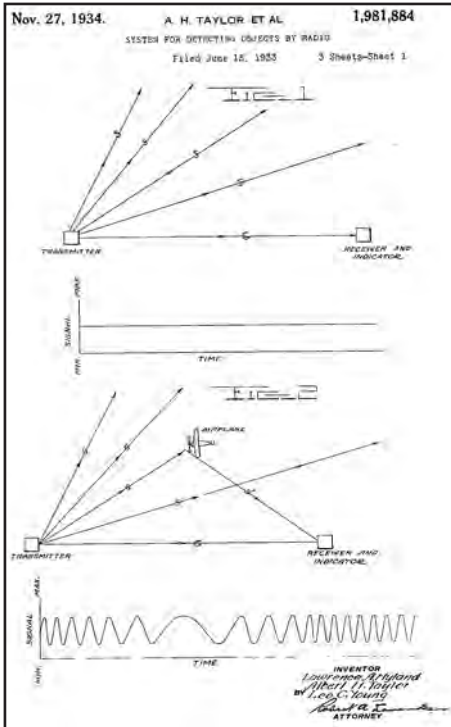


Rocket Hunter. Dr. Ernst Krause, a champion of guided-missile research during World War II, would secure access for laboratory scientists to V-2 rockets that Allied forces captured from the Nazis at the end of the war. For NRL, it would be a transformational development. (*NRL photo Krause(1)*)

Krause’s name came up during Taylor’s inquiry. With a freshly minted Ph.D. in hand, Krause hadn’t done much work in electronics or radio, but he was one of the physics department’s smartest students. That sounded spot-on to Taylor, who also wanted to move quickly. So rather than taking the time-consuming and bureaucratic route of hiring Krause as a civil servant, he offered the young man a one-year contract for \$2,400, an alluring sum at the time. Although he had never been to Washington, DC, let alone NRL, Krause accepted the job at the lab sight unseen. The toughest consequence of that decision, Krause recalled later, was that it meant he would have to leave his girlfriend, Constance Fraser, behind in Wisconsin. Later, the two would marry.¹⁷

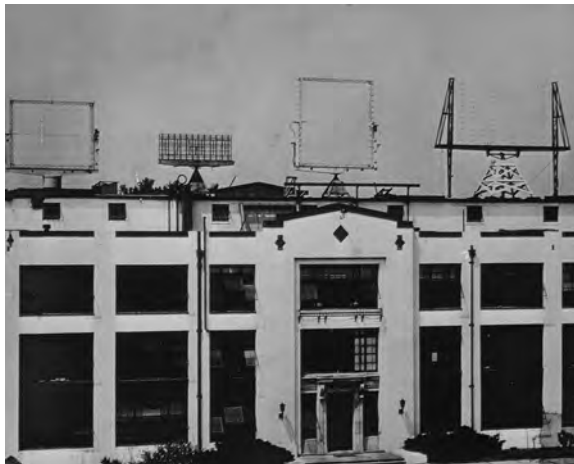
He moved to his new job in September 1938 and, along with a few other new recruits, was quickly brought into a secret world. “Upon arrival there, they took us through the laboratory and one of the things they showed us ... was a then very highly classified project, and that was a working radar.”¹⁸ In late 1934, about a dozen years after Taylor and Young’s discovery of radar’s physical basis, this NRL duo, along with colleague Lawrence A. Hyland, were assigned U.S. patent number 1,981,884 for a “System for Detecting Objects by Radio.”¹⁹ The patent described systems for detecting both ships at sea and flying aircraft; a later generation of NRL engineers would extend the same basic technology for detecting objects in space.

In the few years following the 1933 filing of their seminal radar patent, NRL engineers had made progress, Krause observed. The transmitting unit was on the roof



Radio Vision. A page from the historic radar patent, number 1,981,884 issued on November 27, 1934, to NRL's A. Hoyt Taylor, Leo C. Young, and Lawrence A. Hyland.

of the lab's radio laboratory building. Sticking out was a spiraling antenna element that looked something like a gun barrel and also like a big stretched-out bedspring. Powered by a battery of state-of-the-art, baseball-sized vacuum tubes, it sent out a probing signal of 400 megahertz—about 400 million electromagnetic waves every second, each about 2.5 feet from crest to crest. A separate receiving antenna picked up the reflections and shunted the signals to an indicator device, such as a set of head-



Echo Catchers. Early radar antennas, including CXAM and XAF, atop a building at NRL. (NRL photo 60834(H-136))

phones or a meter, the latter of which rendered the signals visually apparent. “Very clearly, one could see reflections of airplanes and other objects,” Krause recalled.²⁰

The 20-something Krause already was setting on a personal course that within a decade would have transformative consequences for the laboratory’s place in the history of technology. In time, his mark would become apparent in the country’s ability even to survive the harrowing and violent decades to come in both hot and cold wars. The first project in his new position in the lab’s Communications Security Section within the Radio Division, for one, involved adapting for military communications the short radio pulses that radar systems used to ping off of objects such as ships and submarine periscopes.

“We thought this would be a very clever way of conducting secret communications that couldn’t be intercepted,” Krause said, adding that the work led to a series of fundamental patents, some classified by NRL as secret. Some of these advances would prove relevant to ground-to-satellite communication technologies in the coming Space Age. Among the patents were ones for inventions in telemetry, which allowed for the remote transmission of data, measurements, and commands, eventually even from satellites.²¹

Short radio pulses, which were akin to needles in an electromagnetic haystack for any adversary who might want to search for them and listen in, held promise for other militarily pertinent needs. Krause and his NRL coworkers, for example, would exploit the secrecy-preserving power of such pulses to develop IFF (Identification Friend or Foe) technologies that were crucial for preventing incidents of friendly fire in confusing battle contexts. They also tried to use pulse techniques for guiding missiles, but found that reflections of the original pulses from the Earth’s surface could result in the reception by missile guidance systems of multiple identical commands, which was not well advised when it came to controlling projectiles that are intended to blow up in a precise location at a precise time.²²

During World War II in the 1940s, Krause rose quickly in the ranks of the Communications Security Section to become coordinator of the lab’s research in guided missiles. That work had roots extending back to the 1920s in the development of radio-controlled aircraft,²³ early precursors to the 21st-century era drones, including missile-equipped Predators and other unmanned aerial vehicles (UAVs) that have been transforming warfare, intelligence, and homeland security strategies and tactics.

In 1943, the German war machine unleashed a new type of weapon that would force Krause and NRL to develop a new line of expertise, which later would take the laboratory along a trajectory that would make it a leader in the global push to enter the Space Age. “The Germans were dropping some guided missiles [from airplanes] on our ships in the Mediterranean, and it was causing a great deal of panic,” recalled Krause,²⁴ who died in 1989.²⁵

In his history of NRL’s radio work, published in 1979, Louis Gebhard recounted that “the Germans started to use these air-launched missiles, the HS-293 and FX, in

late August 1943 and were able to sink a number of British and American vessels in the Mediterranean Sea and Bay of Biscay.”²⁶ By then, the laboratory already had entered the arena of radio countermeasures, most notably the jamming of enemy radio communications, by identifying the frequency of communication and then burying the intended signal in nonsense noise by flooding the airwaves with a torrent of radio energy in that same frequency. It fell on the laboratory’s shoulders to come up with radio-based countermeasures that would throw off the radio-guidance of the new German missiles.²⁷

“Occasionally one of these devices would hit the stern of a ship, and a few pieces would break off and lie on the deck,” said Krause, noting that these artifacts provided the only information he and his NRL colleagues had regarding the new weapons.²⁸ In addition, he noted, “we had gone to various naval stations in the Mediterranean, which at that point meant the North African coast, in order to discuss with many of the officers and operators our analysis of these German guided missiles, and what they should do to counter them.”²⁹

The NRL contingent reasoned that the Germans could only field a guidance system based on radio knowledge and techniques that were in hand a few years earlier, since anything on the leading edge of radio science would be years away from making it into the field in any practical weapons system. That line of reasoning indicated that the guidance signals were likely in the form of an amplitude modulation (AM) system in which the commands were encoded by varying the strength of the signal, as opposed to frequency modulated (FM) systems in which the command would be encoded by changing the signal’s frequency in specified ways that the receiver would be able to parse.

With that hunch as the basis, the NRL team built a radio receiver that would automatically scan frequencies in search of amplitude-modified ones, as though a hidden hand were turning a radio receiver’s tuning knob through the entire range. A similar technique would become important years later when the lab began building the world’s first ELINT—that is, electronic intelligence—satellites, which is to say satellites designed to detect and characterize electromagnetic signals, including radio and radar signals, of real or potential adversaries.

“The scanning receivers were connected to an oscilloscope,” Krause explained, and the NRL engineers soon learned that the bet on amplitude modulation was a good one. “When a pip came, you stopped the receiver, then you had the frequency of that signal that was coming at you. We knew we had to do all of this in a matter of something like two or three minutes,” a speed that was unheard of at the time. The second half of the countermeasure followed naturally. “You had to intercept this signal, identify it, then get a transmitter cranked to the right frequency, and turn the transmitter on and jam it.” Explained Krause: “[We] built a transmitter whose frequency could be adjusted very quickly, and monitored by the same oscilloscope.”³⁰

The entire countermeasure system took about a month to get together. This was a breakneck pace that couldn't have been otherwise; each additional day during which the German's guided missiles could be deployed was a day of terror and potential death for thousands of Navy sailors and officers. It was in this way that the war experience of sailors at sea and soldiers in the field thousands of miles away could produce a sense of urgency in an R&D laboratory on the outskirts of Washington, DC.

There was a serious gamble in this commitment to an AM-based countermeasure. Some Navy personnel familiar with the German guided-missile attacks raised the possibility that the weapons could have been receiving commands in the form of much shorter infrared wavelengths, rather than radio wavelengths. This was possible, Krause conceded, but he had confidence in his experience and knowledge. "It was my suspicion that the infrared techniques had not been developed that far," he said to bolster his decision to go with the AM framework.³¹ It was a case of a U.S. physicist and engineer getting into the mind-set of enemy physicists and engineers. Best would have been if the Allies could have captured some fully intact guided missiles, or transmitters used to send guidance signals, or documents specifying how the enemy systems worked. In lieu of the hardware and documentation, the NRL team had to make an educated guess. They bet on the AM-based control tactic and built jamming devices based on that hunch.

To hedge against the guesswork, Krause and his engineering team also worked with their Navy counterparts in the war zone to obtain crucial technical intelligence. "Two destroyers, the USS *Davis* and USS *Jones*, were equipped with radio intercept and recording equipment provided by NRL and were sent to the active warfare area to obtain information on frequency range and type of control signals. Analysis of the data obtained provided the basis for the development of a complete, integrated missile intercept-jamming system by NRL," Gebhard recounted.³² These were harrowing missions in which the destroyers served essentially as bait for the sea-based ELINT mission.

"Four complete search and jamming equipments were rushed to completion and shipped by air to Africa for use on ships operating in the Mediterranean," Gebhard recounted. "Two more destroyers, the DD-225 [USS *Pope*] and the DD-227 [USS *Pillsbury*] were outfitted with similar equipment at the New York Navy Yard under NRL guidance before proceeding to active duty protecting convoys from missiles in the same warfare area."³³

With the basic design proven, NRL was able to secure contracts with commercial firms for production of many more of these systems. That sequence, of NRL innovators building prototype units of new technology and then handing these off to industry partners for manufacturing production units, was a pillar of the lab's *modus operandi*. "During the spring of 1944, fourteen equipments of similar design were built for use in the protection of the Normandy invasion fleet. The operators of these equipments were trained by NRL. Fifty equipments, the design of which was modified by

NRL, were also constructed in a rush. Including these equipments, 65 ships equipped for jamming participated in the invasion of southern France. No ships so equipped were ever hit, and the ships were so placed that they protected large numbers of other ships.”³⁴

“We prided ourselves on the fact that we really had accomplished something,”³⁵ Krause recalled. The NRL-developed countermeasures appeared to have taken away the military value of the Germans’ radio-guided bomb. At the same time, Krause and others could see that the strategy of using radio for guidance, command, and control held enormous potential and peril, depending on who had the upper hand. After the war, the mix of technologies behind radio guidance, including antenna design and telemetry, would become foundational in the minds of NRL’s pioneering generation of rocket and then satellite designers and engineers. Krause would be more responsible than anyone for getting all of that going.

As part of his wartime leadership role in the Communications Security Section of the lab’s Radio Division, Krause had undertaken a Mediterranean tour in late 1944 to examine captured German air-to-ground missiles. He made this voyage just months after the war-turning D-Day invasion of Normandy by the Allied powers. It was a transformative experience for him. “Krause had become convinced that German rocketry was far ahead of anything the Allies had,” noted David DeVorkin in his comprehensive history about how German V-2 rockets led to the birth of U.S. space science.³⁶ As Krause saw it, this was a wake-up call to NRL that the lab would have to reposition itself after the war to elevate guided missile development as one of the lab’s primary strengths. Guided missiles, Krause believed, represented an important part of the future of warfare and that meant his lab had to earn a position at the front of the curve.

In the summer of 1945, as the war was winding down, Krause, along with a contingent of NRL colleagues in the Communications Security Section, were back



The V-2 Connection. Designed and deployed by Germany as terror weapons during World War II, V-2 ballistic missiles, like these partially built ones still within the underground V-2 factory known as Mittelwerk, would enable U.S. upper atmosphere researchers to ferry measuring instruments higher than ever before. (<http://www.v2rocket.com/start/chapters/mittel.html>)

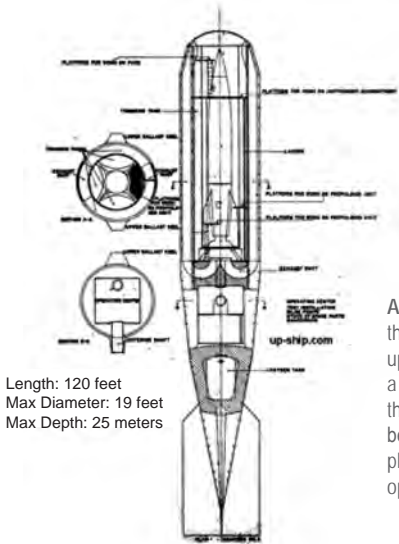
in Europe, collecting intelligence about Germany's wartime developments in guided missiles and other technologies. As part of this mission, Krause was among a cadre of American scientists who interrogated German rocket scientists and engineers who had fled their country's facilities for developing and manufacturing V-2s.³⁷

Krause later recounted his dealings with these rocket engineers. "The group was ... incarcerated in a large girls' dormitory in Garmisch Partenkirchen, a delightful place" near Munich on the border with Switzerland, Krause recalled. "When we went to interview the German technical people in Garmisch ... the intelligence officer said, '*Now, don't you technical fellows start talking. We have to soften these people up first. We have experience in this, and let us get them softened up first and then they'll start talking.*' We agreed. Our first interview was with three of the Germans, two of whom were technical people. As soon as these three Germans sat down and we sat down at the table, the Germans began talking and talking and talking about what they had developed, what further advances they had on the drawing board, what they could do with the V-2 to improve it, to expand it, to extend its range, to improve its guidance accuracy—all of these things they had worked out in great detail, and they wanted to tell us about it ... Pretty soon they pointed out that they had on the drawing boards the complete analysis and design for a V-2 which would extend its range to 3,000 miles ... They argued that if only the Americans would now get behind us, and take them—the group—to the U.S., they could set this up in so many days (they'd worked it all out), and they'd bomb Tokyo."³⁸

At first, Krause and the interrogation team were surprised by the Germans' eagerness to reveal all of these details, but then the reason dawned on them: the Germans had come out of Peenemünde (a V-2 design and assembly location on the Baltic coast), which the Russians had captured, and according to the Geneva Convention, prisoners from that area should have been turned back to whoever had taken the area. "So this whole group was supposed to have been turned back to the Russians," Krause said. "And if there's any one thing that the Germans didn't want, it was to be turned over to the Russians. Anything but that! So they were willing to cooperate to the nth degree."³⁹

For his part, Krause was most interested in German innovations in guidance systems. In his interrogations, his questions focused on technical issues regarding gyros, missile accuracy, and inertial guidance systems.⁴⁰ He picked up a few more stunning details along the way. One of the more frightening discoveries was a plan by German scientists to build a 118-foot-long submerged cylinder that Nazi submarines could tow to the coasts of the United States, erect to a vertical position by flooding one end, and then use the skyward-pointing tube to launch V-2 strikes.⁴¹ Not only was that a reminder of how inventive and dangerous scientists and engineers could be when their talents and imaginations are applied to military causes, but it also highlighted the value of intelligence. You can defend best against the threats you know about.

During this intelligence-gathering tour in Germany, Krause made some contacts that would end up placing NRL at the forefront of America's nascent rocket development efforts in the aftermath of World War II. In particular, Krause crossed paths with Colonel Holger Toftoy, chief of the Enemy Equipment Intelligence Section of the Army Ordnance Department, and Richard R. Porter of General Electric (GE). The Army had contracted GE to organize Project Hermes, a secret effort to develop rockets for the purpose of long-range delivery of munitions just as the V-2s had done for the Nazis.⁴²



A Frightening Plan. The German engineers that developed the V-2 missiles had drawn up plans for a version that could be towed in a capsule across the Atlantic to the coast of the United States, where the capsule could be rendered upright into a floating launching platform. These were never developed into operational units.

When the Army first heard reports about German efforts to develop long-range missiles, in the summer of 1943, it stepped up its own efforts toward that same end. Its sole rocketry experimentation contract was with the Guggenheim Aeronautical Laboratory of the California Institute of Technology (GALCIT).⁴³ This lab had done pioneering work with jet-assisted takeoff (JATO) technologies—including experiments with rockets in the late 1930s—but it suddenly was unmatched to the Army's sense of urgency.⁴⁴ Hence the contract with GE.

But it was Germany that had pushed rocket technology further than any other nation. Its technical know-how and unused rocket hardware at the end of the war were to become windfalls to the Army and, because of Krause's presence, to NRL and the Navy as well. The primary booty, which Toftoy learned about and took control of in April 1945, was at the underground German site known as Mittelwerk. At this site, thousands of slave laborers, many of whom died, had forcibly assembled the V-2 rockets that rained down on Britain and Belgium in the last phases of the war beginning in 1944.⁴⁵

The U.S. Army had captured the subterranean V-2 factory just weeks before the treaty-sanctioned Russian occupation of this part of Germany had actually begun.

Toftoy had no time to waste. As preparations for the transition to the Russians were under way, the Army packed up 360 metric tons of V-2 parts and equipment and shipped the rocketry hardware to White Sands, New Mexico, where the Army was establishing a missile testing ground. The Army wanted to use the V-2s as tools for learning how to handle and launch big rockets.⁴⁶

Krause returned to NRL from Germany in June 1945 with a rocket-filled vision of NRL's near future, although his initial focus was more on guided missiles as weapons rather than rockets for the purpose of conducting space science and operations.⁴⁷ Referring to the impression left on him by his tour in Europe during the war, Krause recalled that "it was very clear to me and to some of my associates that we just had to put much more emphasis on this whole subject of guided missiles. That was where warfare was going."⁴⁸ In late 1945 and early 1946, Krause met repeatedly with an increasing number of NRL colleagues, among them Dr. Milton Rosen and Dr. Homer Newell, to discuss how they might put V-2s to use for studying the upper atmosphere. "Everyone was quickly and favorably disposed to the concept of doing this type of research, because most of us were research type people. And we wanted to get away from warlike efforts," Krause recalled, despite his own continued focus on weapons.⁴⁹ As a first step, DeVorkin noted, Krause "managed to convert his old Communications Security Section into a guided-missiles research and development unit."⁵⁰ Krause was not alone in his enthusiasm. NRL's military director at the time, Commodore Henry A. Schade, had been a major participant and designer of the Navy's technical mission to Europe and was well aware of the German work in guided missiles and rocketry. He joined Krause in the cause to place missile research and development as a centerpiece of NRL's post-war portfolio of research.⁵¹ This quickly would become subsumed in a yet more expansive upper atmosphere research structure. This emerging emphasis at the lab meant that NRL was soon to become home of some of the country's leading-edge rocket engineers and rocket-equipped upper atmosphere scientists.

¹ Edward O. Hulburt, oral history, NRL History Office.

² A.H. Taylor and E.O. Hulburt, "The Propagation of Radio Waves Over the Earth," *Physical Review*, 27, no. 2 (February 1926): 189–215.

³ P. Binning and J. Mddour, "A Brief History of NRL's Early Firsts in Spaceflight," *Advances in the Astronautical Sciences*, 129 (2008): 1233–1250.

⁴ H. Henry Stroke, *Physical Review: The First 100 Years: A Selection of Seminal Papers and Commentaries* (New York: AIP Press/Springer Verlag, 1995).

⁵ Gregory Good (ed.), *The Earth, the Heavens and the Carnegie Institution of Washington* (Washington, DC: American Geophysical Union, 1994), pp. 139–141.

⁶ http://www.nasa.gov/centers/marshall/news/news/releases/2003/03-125.html_prt.htm.

⁷ Robert Goddard, "A Method for Reaching Extreme Altitudes," *Smithsonian Miscellaneous Collection*, vol. 71, no. 2 (Washington, DC: Smithsonian Institution, 1919).

⁸ Homer E. Newell, *Beyond the Atmosphere: Early Years of Space Science* (NASA SP-4211) (Washington, DC: National Aeronautics and Space Administration, 1980), pp. 27–28; Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: National Aeronautics and Space Administration, 2000), pp. 1–2.

⁹ Newell, *Beyond the Atmosphere*, p. 10.

¹⁰ Bruce Hevly, "Building a Washington Network for Upper Atmosphere Research," in *History of Geophysics*, vol. 5, *The Earth, the Heavens and the Carnegie Institution of Washington* (Washington, DC: American Geophysical Union, 1994).

¹¹ Bruce Hevly, *Basic Research Within a Military Context: The Naval Research Laboratory and the Foundations of Extreme Ultraviolet and X-ray Astronomy, 1923–1960* (Baltimore, MD: Johns Hopkins University, 1987), pp. 51–52.

¹² David H. DeVorkin, *Science with a Vengeance: How the Military Created the U.S. Space Sciences after World War II* (New York: Springer-Verlag, 1992), p. 9.

¹³ <http://www.physics.wisc.edu/sites/physics/files/news98.pdf>; https://en.wikipedia.org/wiki/Albert_H._Taylor.

¹⁴ Ernst Krause, oral history conducted by David DeVorkin in Newport Beach, California, on August 10, 1982 (AIP, <http://www.aip.org/history/ohilist/28022.html>).

¹⁵ http://www.ieeehn.org/wiki/index.php/Albert_H._Taylor.

¹⁶ Krause, oral history.

¹⁷ Krause, oral history.

¹⁸ Krause, oral history.

¹⁹ U.S. Patent 1,981,884, issued November 27, 1934.

²⁰ Krause, oral history.

²¹ Krause, oral history.

²² Krause, oral history.

²³ Ivan Amato, *Pushing the Horizon: Seventy-Five Years of High Stakes Research and Technology at the Naval Research Laboratory* (Washington, DC: Naval Research Laboratory, 1998), p. 168; Angelina Long Callahan, "Reinventing the Drone, Reinventing the Navy," *Naval War College Review* 67, no. 3, (Summer 2014): 98–122.

²⁴ Krause, oral history.

²⁵ <http://www.nytimes.com/1989/08/29/obituaries/ernst-h-krause-76-aerospace-executive.html>.

²⁶ Louis A. Gebhard, *Evolution of Naval Radio-Electronics and Contributions of the Naval Research Laboratory*, NRL Report 8300 (Washington, DC: Naval Research Laboratory, 1979), p. 303.

²⁷ Gebhard, *Evolution of Naval Radio-Electronics*, pp. 300–307.

²⁸ Krause, oral history.

²⁹ Krause, oral history.

³⁰ Krause, oral history.

³¹ Krause, oral history.

³² Gebhard, *Evolution of Naval Radio-Electronics*, p. 303.

³³ Gebhard, p. 303.

³⁴ Gebhard, pp. 303–304.

³⁵ Krause, oral history. After the war, as part of a technical team charged with finding out as much about German wartime weapons research as possible, Krause learned that at least some of the failures of the guided weapons also likely were due to incompetence on the part of the military personnel, who had procured the weapons from the scientists and engineers who had designed them but did not ask for assistance in using them. "So whether or not our countermeasures were really successful, or whether it was disorganization among the Germans that really stopped these missiles at this point is very difficult for me to say," Krause said.

³⁶ DeVorkin, *Science with a Vengeance*, p. 48.

³⁷ Krause, oral history. This was complementary to a larger technology reconnaissance effort known as Operation Paperclip. See also Michael J. Neufeld, *Von Braun, Dreamer of Space, Engineer of War* (New York: Alfred Knopf, 2007).

³⁸ Krause, oral history.

³⁹ Krause, oral history.

⁴⁰ DeVorkin, *Science with a Vengeance*, p. 28.

⁴¹ Bruce Hevly, “Building a Washington Network for Upper Atmosphere Research,” references this sea-based variation on the V-2 theme to Marvin Lasky, “Historical Review of Undersea Warfare Planning and Organization 1945–1960, with Emphasis on the Role of the Office of Naval Research,” *Journal of Underwater Acoustics*, 16 (1976).

⁴² DeVorkin, *Science with a Vengeance*, pp. 47–48.

⁴³ DeVorkin, pp. 47–48.

⁴⁴ DeVorkin, pp. 47–48.

⁴⁵ DeVorkin, p. 45 and footnote 4, p. 54.

⁴⁶ Amato, *Pushing the Horizon*, p. 168; DeVorkin, *Science with a Vengeance*, p. 48.

⁴⁷ DeVorkin, *Science with a Vengeance*, p. 48.

⁴⁸ Krause, oral history.

⁴⁹ Krause, oral history.

⁵⁰ DeVorkin, *Science with a Vengeance*, p. 48.

⁵¹ DeVorkin, p. 49.

3

SCIENCE FIRST

Since guided missiles were to become important additions to national arsenals around the world, Dr. Ernst Krause was adamant that NRL's engineers would keep the country on the leading edge of this new category of high-tech weaponry. "I felt at least a quarter of the laboratory's effort should be devoted to missiles, because it was the weapon of the future," Krause told a historian years later.¹ In this same post-World War moment, however, NRL's leadership wanted to place renewed emphasis on basic science on the lab's grounds, a sentiment that was in place before the war but had been supplanted by immediate wartime equipment research, development, testing, and deployment needs in the first half of the 1940s.² In this context, Krause and the lab's military director Commodore Henry Schade began pushing the idea of rockets as exciting new tools that would bring to the lab a new era of upper atmosphere research. With rockets, NRL's scientists finally would have a means of lofting measuring instruments directly into the ionosphere and beyond the obscuring, even blinding, effects of the atmosphere. Edward O. Hulburt's modest push for rocket-based science 20 years earlier was looking rather prescient.

What was different now was that NRL, thanks to Krause, had secured the means to bring rockets into its research portfolio. In a laboratory report dated December 3, 1945, which served as a proposal toward this end, Krause wrote, "There is now available to us a new tool, the rocket, which already has reached altitudes four times as high as a balloon and ten times as high as an airplane."³ His in-lab lobbying paid off. On December 17, what previously had been known at the lab as the Guided Missiles Subdivision of the Electronic Special Research and Development Division, became known (by the beginning of 1946 after some organizational shifting) as the Rocket Sonde Research Section of Radio Division I.⁴ The word sonde refers to instrumented probes that automatically send data about their surroundings.

Unlike the first rockets to carry satellites into orbit, beginning with the Soviet launch of Sputnik 1 on October 4, 1957, a rocket sonde merely shoots as high as its fuel plus a period of unfueled coasting will take it before falling back to Earth in the second half of a parabolic trajectory. It's a trip that lasts only a few minutes at best.

Krause was assigned to head the new section. Its functions were defined in Laboratory Order No. 46-45 as follows: "to investigate the physical phenomena in and the properties of the upper atmosphere with a view to supplying knowledge which will influence the course of future military operations." To carry out these functions, the

Section was charged with doing the basic research to develop the “techniques, instrumentation, and devices required.”⁵

The Rocket Sonde Research Section (RSRS) would become NRL’s institutional beachhead for the lab’s charge in the 1950s into the Space Age. It would influence much of the basic research that over the next few decades would put NRL more visibly on the scientific map than it had ever been before. The rocket sonde researchers would work closely with other groups in Radio Division I, including a Radio Wave Propagation Group led by John Hagen, whose wartime radio investigations would help open up the lab’s pathway to radio astronomy⁶ and who would become hugely influential in bringing the world into the Space Age. This role would place him squarely in the media spotlight with an excruciating failure—indeed, one of the most embarrassing moments in the history of the Cold War and a decidedly trying time for NRL—in the late 1950s⁷ (see Chapter Seven). Hagen would later summarize NRL’s approach to the Space Age as a three-stage structure: “The Naval Research Laboratory was born out of World War I. It grew to maturity in preparing for World War II, excelling in its achievement during the War. It blossomed into a full-fledged scientific institution in applying the talents of its people after the war.”⁸ A standout petal on this blossom was rocket-based science, made possible by the rocket fever born in Krause during the war.

When the Rocket Sonde Research Section formed, the Army already had contracted the Jet Propulsion Laboratory (JPL)—which budded from the California Institute of Technology during World War II and is now operated for NASA by that institute—to develop missile and rocket technology. In October 1945, JPL had scored an exciting success when it launched its WAC Corporal to a height of 70 kilometers (44 miles), a record at the time and tantalizingly close to the ionosphere.⁹ Krause too had dealings with JPL, in part because he wanted several of his staff, including Dr. Milton Rosen, who would become a giant in rocket engineering at NRL and then NASA, to spend time at Caltech to get up to speed on the latest techniques in rocket development.¹⁰

As it turned out, the WAC Corporal¹¹ was too small to carry enough of a scientific payload high enough to meet NRL’s rocket sonde researchers’ needs. It could carry only about 25 pounds of payload to altitudes of about 20 miles, far below the upper reaches of the atmosphere that so interested the NRL investigators.¹² So Krause and his team were poised at the end of 1945 for the long and novel haul of developing a rocket that could meet their specific needs. To them, NRL was destined to become a place where leading-edge rocket engineering would have to be done if they were going to do the science the lab’s scientists wanted to do.

Then on January 7, 1946, a most welcome opportunity opened up for NRL’s upper atmosphere scientists. That’s when Krause and other members of the RSRS learned at a meeting convened by Lieutenant Colonel James G. Bain of the Army Ordnance Department about the Army’s imminent plan to launch infamous V-2 rockets, as-

sembled from the captured cache of V-2 parts, at the then-under-construction White Sands Proving Ground in New Mexico.¹³ The Army's interests in firing the rockets (for which the NRL team initially believed there were enough intact parts on hand to assemble perhaps 75 vehicles)¹⁴ largely were military in nature—to learn how to handle, use, and track rockets of V-2 dimensions that could carry explosive payloads. But Bain also indicated that the Army was interested in gathering data about the upper atmosphere. If he and his Army brethren were going to be shooting rockets into the upper atmosphere, they needed to know what that place was like—its temperature ranges, compositions, and pressures.¹⁵ This was a research endeavor the Army was ill-equipped to pursue on its own.

The stars were aligning for NRL's full embrace of rocket technology. There was the U.S. Army about to fire the world's biggest and most powerful rockets, but they had no atmospheric measurement tools to loft skyward on them. And there was NRL with a new basic research section aiming to do rocket-borne scientific studies of the upper atmosphere, yet expecting to wait perhaps years before having a suitable rocket in hand made by a not-yet-specified contractor.

At the behest of Krause, a follow-up to the January 7 meeting took place on January 16 at NRL. Forty-one representatives from a dozen institutions attended. What emerged from that was a research-coordinating body, known as the "V-2 Panel" and more formally as the Upper Atmosphere Rocket Research Panel (UARRP), with Krause assuming a leadership role.¹⁶ These developments placed NRL at the titular forefront of rocket-borne research in the United States. NRL's Rocket Sonde Research Section became part of a tight club composed of other government and academic groups with kindred interests to take part in the effort to measure properties of the upper atmosphere. It was a plan that "was enthusiastically received and accepted" at the lab, Krause wrote in his research group's first report on their V-2 work.¹⁷

It was a moment of convergence for NRL, when an emerging technology that could change the course of military tactics and strategy (if there were no defenses against missiles, these weapons could render naval vessels ineffective, for example) would provide the means for conducting upper atmosphere research to literally new heights and for making sure NRL researchers were in the forefront of that emerging science.

NRL had company in its interest in rocket-borne research. The Army Signal Corps Laboratory, which had developed early radar systems alongside NRL in the 1930s and during World War II, was getting in on the wave. So was the Applied Physics Laboratory (APL), a legacy of the wartime research coordination organization, the National Defense Research Committee (NDRC). Run by Johns Hopkins University, APL's initial World War II mission was the development of proximity fuses to help Navy ships defend more effectively against air attacks. Other players in on the rocket action were General Electric (which the Army contracted to help run the missile and rocket launchings at White Sands Proving Ground),¹⁸ the National Bureau of Stan-



V-2s for Science. A V-2 rocket, captured from the Nazis at the end of World War II, is readied for launch by Army engineers in 1946 at the White Sands Proving Ground in New Mexico. NRL jumped at the invitation to use V-2s for upper atmosphere research. The Nazis had used the rockets in Europe as a terror weapon during the war. (Photo image1_132-11r)



Assembly work in a White Sands Proving Ground hangar. (NRL photo 60834(H-585-6))

dards (renamed in 1998 as the National Institute of Standards and Technology, or NIST), and several universities.

Just three months after the formation of the V-2 Panel, on April 16, 1946, the first American-launched V-2 roared skyward from White Sands. Perhaps to consolidate NRL's leading role in pushing rocket engineering forward, Krause arranged for NRL to provide telemetry and radio-control equipment for these early rockets and to custom-design and produce the vehicles' nose cones by way of the Naval Gun Factory.¹⁹ Some 60 more V-2s would follow suit over the next four years. "The rockets carried a total of twenty tons of scientific instrumentation to altitudes ranging from 50 to 100 miles," according to a Navy-produced chronicle of the military service's role in the U.S. space program.²⁰

NRL's Dr. Herbert Friedman, whose astronomy research and discoveries would earn him a place among the titans of astronomy, witnessed many of these launches: "No matter how many times you witnessed it, the launch of these rockets was always inspiring. After the short-lived bursts and rapid acceleration that characterized the firings of small rockets, the slow, majestic rise of the V-2 and the sudden vanishing of the roar of the rocket in the eerie quiet of burnout was a breathtaking experience. Silent, snaking vapor trails marked the passage of the rocket through the stratosphere, and sound returned only near landing when shock waves reverberated from the mountains."²¹



An Astronomy Giant. Dr. Herbert Friedman, shown here in 1961, pioneered rocket-based measurement of solar radiation in the late 1940s and 1950s on his way to becoming one of the world's most noted astronomers. Author of several books on astronomy, he was a successful popularizer of science too. *(NRL photo Friedman(9))*

The V-2 based research program had a healthy portion of difficulty, however. Though far more powerful than JPL's WAC Corporal, the V-2 was designed to transport explosives into enemy territory, not to carry scientific instrumentation to great atmospheric heights. "Eleven hundred pounds of lead have been poured into the nose of a V-2 when the instrument load was insufficient to provide static stability," recalled Milton Rosen and Richard Snodgrass, members of Krause's Rocket Sonde Research Section.²² The V-2's technology also was replete with bugs, not made any easier by the fact that these were German-designed vehicles being assembled in the United States

with American crews, albeit with considerable help from some of the very German scientists and engineers that had developed the missile in the first place. According to Friedman, “The first five of the huge rockets all returned nose down in streamlined flight and buried their pulverized remains in craters about 30 feet deep and 80 feet in diameter. One reversed direction from north to south and headed for El Paso, Texas. It crossed the Mexican border and struck next to Tepeyac Cemetery, about a mile and



Science Warheads. To adapt captured V-2 rockets for upper atmosphere research, NRL engineers designed replacement warhead assemblies that could accommodate scientific instruments. Shown here are two NRL-made science “warheads,” including one in a laboratory where a cosmic ray telescope on the warhead is being tested for a March 7, 1947, launch. Forty-five Geiger-Muller counters and more than a half ton of lead were used in this experiment. (Top: *Nosecone1_1947*; “*The Navy Upper Atmosphere Research Program With Rocket Vehicles, Part 1*,” published on April 10, 1947; Bottom: *NRL photo 60834(H-297)*)

a half from Juarez. The impact barely missed a warehouse full of commercial blasting powder and dynamite. This event may be recorded as the first U.S. ballistic missile strike on foreign soil.”²³

Krause and others in the rocket science arena always had considered the V-2s as stopgap vehicles for a new field of rocket-borne research that would outlast the supply of the German missiles. Even as preparations for the first White Sands V-2 launches were under way, Krause and Rosen of NRL teamed up with the Applied Physics Laboratory to jointly procure an APL-developed scientific rocket—the Aerobee. The vehicle featured an engine designed by the Aerojet Engineering Company²⁴ in southern California and relied on additional engineering and production work by Douglas Aircraft (later to be combined with McDonnell Aircraft to form McDonnell-Douglas) and JPL. Twenty feet high and capable of reaching a height of 75 miles, it was simpler and cheaper to launch, compared to the V-2s, whose supply was limited. It could hoist 150 pounds of payload in its 88-inch-long nose cone.²⁵ For the longer-term supply of more capable rockets, NRL began designing its own rocket, the Viking,²⁶ for which Rosen would be designated the project director.²⁷ The first successful Viking launch would take place from White Sands in 1949.

Despite the uncertainty that some V-2 launches amounted to, NRL researchers quickly began reaping the kinds of scientific riches they had envisioned would come with rockets. The first to bring home gold was Dr. Richard Tousey and his colleagues in the Optics Division, who had become infected with the enthusiasm of Krause’s Rocket Sonde Research Section.



Trial and Error. The early V-2 tests for upper atmospheric research ended in crash landings that pulverized the scientific warheads and everything in them. (NRL photo 67718)



Sun Watcher. Dr. Richard Tousey, an optical scientist at NRL, examines an instrument-laden nose cone before a V-2 launch at White Sands Missile Range in New Mexico. (NRL photo newimage0(4))

Tousey, a Harvard-educated optical physicist and life-long bird watcher,²⁸ was hired into the NRL Optics Division in 1941 where he soon dove into wartime projects centered on atmospheric challenges to navigation by starlight and would later leverage his graduate work on ultraviolet (UV) radiation in the vacuum to designing instruments for studying the sun's UV spectrum.²⁹ It is no surprise that Hulburt, the first researcher hired at NRL with the express freedom to choose his topic as an academic scientist might, would be the one to hire scientists like Tousey and Friedman. Both of these men would realize the ideal of NRL as a bastion of basic research unfolding side-by-side with research and engineering applied to military ends and national security.

When word of the lab's access to V-2s started getting around NRL beyond the Rocket Sonde Research Section, Hulburt, who had been thinking about rockets longer than anyone at NRL, immediately saw immense potential.³⁰ After all, he had devoted much of his research to revealing and measuring the physical features of the upper atmosphere that affect long-distance communication. This led to important results including empirically derived protocols enabling Navy radio operators to determine what wavelengths to use at different times and locations. Useful as that may have been, Hulburt and his colleagues still wanted to understand the atmospheric phenomena that required them to develop such protocols in the first place.

It was widely known that radiation from the sun was what set these upper atmosphere mechanisms—including the fluctuating character of the ionosphere—into motion. A theoretical understanding of what was going on had been elusive, however. A big part of the problem was that so much of that solar radiation could never make it beyond the absorptive upper reaches of the atmosphere to measuring instruments below or to ones carried even beyond airplane altitudes via research balloons. Hulburt could see that rockets could break through the blindness imposed by the very atmosphere he wanted to understand.

Hulburt challenged Tousey to put a wavelength-recording instrument, a spectrograph, on a V-2 at White Sands.³¹ That way, as he and Tousey both knew, an instrument capable of detecting the spectrum of ultraviolet radiation would for the first time soar above the stratospheric ozone layer which absorbs UV wavelengths shorter than 3,000 angstroms. The visible spectrum spans between about 3,000 and 7,000 angstroms. The ultraviolet spectrographs that Tousey and his NRL coworkers designed and built contained special gratings of ultrafine lines that diffract different wavelengths of UV radiation at different angles, thereby spatially separating the many component wavelengths of a UV source such as the sun. The spectrograph directed these separated components onto a photographic plate. The resulting exposures represented the source's rainbow of UV light, otherwise known as a UV spectrum.

Tousey's interest in measuring the extreme ultraviolet radiation, the portion of UV light that approaches the even shorter-wavelength X-rays, began in his graduate days when he worked under Harvard University professor Theodore Lyman. Dr. Lyman had developed techniques to measure UV spectra emitted by excited chemical species such as gaseous hydrogen atoms, which he would confine within a vacuum chamber so that there would be no air molecules to absorb the more extreme UV wavelengths. The laboratory preparation was Lyman's way of emulating the hydrogen in space. One of the more prominent hydrogen-derived wavelengths, which astronomers had observed to be strongly absorbed as the hydrogen emissions in space make their way to detectors on Earth, became known as Lyman-alpha.

Atmospheric researchers began to suspect in the 1920s that Lyman-alpha emission, measured at 1,215.7 angstroms, might play a large role in electron-energizing mechanisms in the ionosphere. This was not merely an academic issue, since high-frequency radio fadeouts appeared linked to changes in the ionosphere wrought by solar activity. The sun is composed primarily of hydrogen.

One mechanism proposed to account for the fadeouts, which could interfere with naval communication for days, involved the injection of solar energy (in ultraviolet and X-ray ranges) into atoms in the Earth's upper atmosphere. Based on gas-phase experiments in ground-based labs, like those of Professor Lyman, atmospheric scientists expected this process to generate populations of free electrons in certain regions of the upper atmosphere, thereby affecting the ionosphere. If that indeed were the case, it would help explain such phenomena as fadeouts that coincide with high sunspot ac-

tivity. Without direct measurement above most or all of the stratospheric ozone layer where most of the extreme ultraviolet radiation (including Lyman-alpha) is absorbed, however, no one could tell for sure if this proposed mechanism was anything more than an intellectually satisfying story. Hulburt, Tousey, and their colleagues at NRL hoped a UV spectrograph in the nose cone of a V-2 would help them to separate fact from fiction in this scenario.

Their first try took place on June 28, 1946. It was the sixth V-2 shot. The rocket lifted off from its launch site at White Sands and then careened back to Earth. With nothing to slow its descent, its impact created a crater from which virtually nothing from the rocket, including the spectrograph, was recovered.

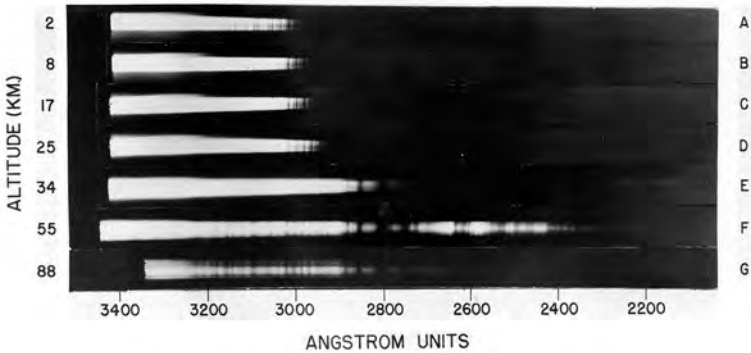
Failures and frustration always have been parents of invention, and the steps Tousey and colleagues took to ensure success in future V-2 firings presaged the sort of innovation that would become part and parcel of the U.S. space program. For example, Tousey realized that conventional spectrograph designs using prisms to disperse incoming light into its component wavelengths would not work in the setting of a V-2; there would be no way to keep the prism, which would have to be located in a specific place on the rocket's spinning nose cone, aimed in the direction of the sun. So Tousey and his colleagues devised a system in which glass beads, about the size of shotgun pellets, embedded in openings dispersed in the nose cone would collect solar light like fisheye lenses no matter which way the nose cone was oriented. The light from the beads would shine onto a diffraction grating—a flat, finely ruled optical element—which would then spread the light, without the need for other optical elements, onto a photographic film.³²

As Tousey's science-minded team devised the new spectrograph so that it could obtain the desired UV data in a rocket whose orientation could not be controlled, Krause's more engineering-minded staff worked out the myriad challenges to integrating the new spectrograph design into the V-2 nose cone space, which during World War II had contained deadly explosive warheads. NRL was one of the few places in the country that had on its staff the diversity of expertise, including precision manufacturing and machining capabilities, required for solving all of the novel problems associated with rocket-based science.

The twelfth V-2 flight, which took place on October 10, would reveal how this teamwork could pay off. Not only did Tousey equip the vehicle with a new spectrograph, but this time the NRL team managed to mount the instrument on one of the rocket's four stabilizing fins rather than in the more vulnerable nose cone. Also, in another tactic to reduce the energy of impact, operators remotely blasted the falling V-2 into less-streamlined parts that would descend more slowly.

This time, Tousey was able to retrieve the spectrograph. And it harbored data no one had seen before—the solar UV spectrum down to 2,200 angstroms. This previously unmeasured portion of the sun's UV emission spectrum was called the “new UV.” A subsequent V-2 flight on March 7, 1947, yielded another 300 newly observed UV lines

between 2,200 and 3,000 angstroms. With these, and knowledge of how atoms absorb and emit light, the NRL scientists were able to identify the presence of 17 chemical elements in the sun,³³ yet another scientific payoff of lofting measuring instruments higher than ever before. These newly observed components of the solar spectrum were the shortest UV wavelengths ever measured from the sun. Even so, this expanded spectrum still did not reach far enough to include the Lyman-alpha line, an extreme UV wavelength a full 1,000 angstroms shorter than any in the “new UV.”



THE FIRST SOLAR ULTRA-VIOLET SPECTRA RECORDED ABOVE THE OZONE LAYER
 Photographed from a V-2 Rocket on October 10, 1946
 by the
 U. S. Naval Research Laboratory

Radiation Revealed. When NRL's scientists began installing radiation detectors on V-2 rockets, they quickly obtained novel data. Shown here, from a launch on October 10, 1946, is the first ultraviolet spectrum from the sun's radiation ever recorded above the atmosphere. (*NRL photo 60834(H-293)*)

These first flights only whetted the scientists' appetites. After all, the atmosphere not only relentlessly screened UV radiation below 3,000 angstroms from Earth-bound and sky-lofted instruments, but it also blocked transmission of many of the even higher-energy cosmic emanations, including X-rays and gamma rays. The same was true for much of the infrared radiation and low-frequency radio waves below 20 kilohertz. In effect, before 1946 and the first V-2 flights, the atmosphere had blinded scientists to a plethora of astronomical “colors” that could reveal previously unknown phenomena associated with the atmosphere, the sun, the rest of the cosmos, and militarily relevant issues such as problems with long-distance, high-frequency radio communication.

Spectrographic measurement of those shorter and fainter wavelengths was hampered by the V-2's tendency to spin and wobble as it rode out its parabolic path from launch to peak to crash site. Although Tousey's spectrographs enabled NRL scientists to record more of the sun's UV emission than ever before, pushing the spectrograph's view even further would require that the instrument's optics point more stably and for longer periods of time at the sun than could the optical beads.

To gather better and more revealing data, the NRL team turned to a “sun follower,” a gadget that would rely on a photoelectric tube to monitor the location of the sun

with respect to the rocket's orientation and then send signals to a mechanical servo system that would reorient the spectrograph in the nose cone so that it would spend more precious seconds of each fleeting V-2 flight actually pointing toward its solar target.

"Most of the sun follower's electronic and mechanical systems were adopted directly from a radar tracking unit developed at MIT's Radiation Laboratory during the war, with the substitution of a light-sensitive receiver for the radio-frequency radar system," according to historian of technology Dr. Bruce Hevly, who carefully investigated NRL's role in early rocket-based astronomy.³⁴ The NRL team was quickly able to adapt the wartime radar tracker into a peacetime sun tracker.

Unfortunately, a string of five consecutive launch failures involving V-2 rockets and one newly available Aerobee rocket frustrated Tousey and his colleagues in their attempts to be the first to measure the coveted Lyman-alpha emission. Better fortune befell a group at the University of Colorado, which had developed a less weighty sun follower under an Air Force contract.³⁵ Their stabilized spectrograph finally did bag the world's first Lyman-alpha measurements of the sun in 1953. Tousey followed the Colorado scientists' achievement with a definitive observation of his own of Lyman-alpha radiation just months later in 1954.

Amidst all of the bad luck with the rockets—or one could equally well say, amidst the steep learning curve—in the late 1940s, Tousey's team managed to develop an alternative means of measuring not only UV radiation but also a portion of the X-ray spectrum (with shorter wavelengths than UV) that abuts the extreme edge of the UV spectrum. The principle of this alternative measurement was thermoluminescence.³⁶ UV or X-ray radiation would hit carefully chosen phosphors, which are chemicals that emit light when exposed to radiation. The principle at work was much the same as that inside the cathode ray tubes of televisions in which electrons shot from the tube would hit light-emitting phosphors coated on the inside of the TV's glass screen. For Tousey, the phosphor-generated light due to incoming UV light and X-rays would, in turn, expose film. The intensity of the exposure qualitatively indicated the intensity of the radiation. And by using different filters that would allow only pre-selected ranges of radiation through to the phosphors, Tousey and his colleagues could determine the approximate wavelengths of the incoming radiation.

Of the six V-2s that Tousey equipped with thermoluminescence systems, he was able to retrieve data from four. The first success was on February 17, 1949, when the sun was particularly active. It revealed the unusual presence of X-rays below an altitude of 79 miles. None of the other experiments duplicated that result, probably because none of the others flew at a time when solar activity was high. During that first success, measurements from ground-based instruments simultaneously monitored ionospheric disturbances. This happy concurrence would help the NRL scientists discern the different atmospheric roles played by extreme UV radiation and X-rays from the sun.

Five weeks after the flight, the Navy touted the meaning of the result in a press release. It harkened back to the lab's earliest days when the pioneering NRLers studied skip distances. [The] "intense . . . ultraviolet rays apparently produce the ionospheric layers necessary for long distance radio transmission," the release suggested, "while sudden bursts of X-rays apparently cause radio fadeouts and disrupt radio communication . . . On flights when intense X-rays were detected, solar flares were observed by astronomers and radio fadeouts occurred all over the world during the time the rocket was in flight."³⁷

All four successful thermoluminescence experiments detected radiation in a swath of ultraviolet wavelengths including the Lyman-alpha line. With the new data, Tousey's team was able to deduce the intensity of solar-derived extreme-UV radiation, and thereby the amount of energy the sun injects into the atmosphere. Their findings confirmed previous suspicions by others that a disproportionate amount of solar UV radiation is in the sub-3,000 angstrom regime. They also were able to calculate ozone concentrations at different atmospheric heights up to about 70 kilometers.³⁸

The thermoluminescence data were intriguing. But they were the result of a largely indirect, qualitative measurement because exposure of the spectrograph's film, which was the data-recording medium, was due directly to light from the thermoluminescence process, not from the incoming solar radiation. Therefore, observations of exposed film were not enough to determine exactly which UV or X-ray wavelengths were reaching the instrument's phosphors. There was plenty of incentive for other researchers, including Herbert Friedman, to develop more direct and quantitative techniques for measuring solar radiation at various levels of the atmosphere.

Just as A. Hoyt Taylor's technological interest in high-frequency radio communication had steered the Radio Division into scientific issues, such as the way the ionosphere affects the propagation of high-frequency radio waves, the interest of Krause and his colleagues in the Rocket Sonde Research Section in rockets for upper atmosphere work was opening new scientific doors, this time in astronomy.³⁹ In a move that reflected the lab's growing and diversifying R&D portfolio, Krause left the Rocket Sonde Research Section in 1947, along with about 20 others, when his responsibilities in the arena of nuclear weapons testing became a higher priority.⁴⁰ He handed the rocket sonde baton to Homer Newell, under whom Milton Rosen would oversee booster development for the V-2's sequel, the Viking, as well as launch vehicle development for that project's follow-on, the ultra-high-profile Project Vanguard.

Top leadership at NRL was evolving in a way that would be friendly to spaceward aspirations. In 1949, for one, Hulburt shed his role as head of the Optics Division to become the first civilian Director of Research at NRL, an administrative evolution in line with the laboratory's concerted effort to emulate the academic model of research. With the origin of his own rocket fever anchored in the early launches of Robert Goddard in the mid-1920s, Hulburt's ascent also ensured that rockets would continue rising in importance and profile at NRL.

While Tousey and Friedman were becoming world-class leaders in rocket-borne upper atmosphere and astronomy research in the first half of the 1950s, NRL as an organization was about to take one of the deepest plunges yet—or more accurately, one of the highest leaps—into the still young field of rocket engineering.

¹ Ernst Krause, oral history conducted by David DeVorkin in Newport Beach, California, on August 10, 1982 (AIP, <http://www.aip.org/history/ohilist/28022.html>).

² A. Hoyt Taylor, *The First Twenty Five Years of NRL* (Washington, DC: Navy Department, 1948), p. 53; Ivan Amato, *Pushing the Horizon: Seventy-Five Years of High Stakes Research and Technology at the Naval Research Laboratory* (Washington, DC: Naval Research Laboratory, 1998), especially Ch. 6; Bruce Hevly, *Basic Research Within a Military Context: The Naval Research Laboratory and the Foundations of Extreme Ultraviolet and X-ray Astronomy, 1923–1960* (Baltimore, MD: Johns Hopkins University, 1987), pp. 70–92.

³ Ernst Krause, “Report on a Proposed Guided Missile Program of the Naval Research Laboratory,” December 3, 1945. See also David H. DeVorkin, *Science with a Vengeance: How the Military Created the U.S. Space Sciences after World War II* (New York: Springer-Verlag, 1992), p. 79.

⁴ Hevly, *Basic Research*, pp. 111–139; Naval Research Laboratory, “The Navy Upper Atmosphere Research Program with Rocket Vehicles, Part 1,” Washington, DC, April 10, 1947.

⁵ Laboratory Order No. 46–45, Navy Department, Office of Research and Inventions, Naval Research Laboratory, Washington, D.C., December 1945; Amato, *Pushing the Horizon*, p. 169.

⁶ Hevly, *Basic Research*, p. 113.

⁷ Hugh Sidey, “The Man Who Took the Beating for Vanguard,” *Life Magazine*, March 31, 1958, p. 35.

⁸ Hevly, *Basic Research*, p. 92.

⁹ DeVorkin, *Science with a Vengeance*, pp. 169–171; <http://www.jpl.nasa.gov/jplhistory/early/wartime.php>.

¹⁰ DeVorkin, *Science with a Vengeance*, p. 68.

¹¹ The early Army rockets were named after enlisted ranks, as in Private, Corporal, and Sergeant. The WAC Corporal served as a scientific rocket rather than a weapon and it was smaller, not larger than its predecessors. The WAC acronym referred to “Without Active Control,” the rocket’s originators later claimed (see DeVorkin, *Science with a Vengeance*, p. 169).

¹² http://airandspace.si.edu/collections/artifact.cfm?object=nasm_A19590009000.

¹³ DeVorkin, *Science with a Vengeance*, p. 61.

¹⁴ “The Navy Upper Atmosphere Research Program with Rocket Vehicles, Part 1,” pp. 6–7.

¹⁵ A good compilation of the many measurements the NRL researchers aimed to make with rocket-borne instruments is in “The Navy Upper Atmosphere Research Program with Rocket Vehicles, Part 1.” Another source that does the same thing but looking backwards after a dozen years of upper atmosphere research is this 18-page document, “History of the Upper Air Rocket Research Program at the Naval Research Laboratory, 1946–1957.”

¹⁶ DeVorkin, *Science with a Vengeance*, p. 63. The UARRP underwent several name changes, including, early on, “the V-2 Panel.” See DeVorkin, p. 168, and <http://history.nasa.gov/SP-4211/appen-c.htm>.

¹⁷ Ernst Krause, Rocket Sonde Research Section Report.

¹⁸ Hevly, *Basic Research*, p. 122. White Sands Proving Ground was renamed White Sands Missile Range in 1958.

¹⁹ Hevly, *Basic Research*, p. 136; “The Navy Upper Atmosphere Research Program with Rocket Vehicles, Part 1,” pp. 38–45.

²⁰ Applied Research Laboratory, The Pennsylvania State University (ed.), *From the Sea to the Stars: A Chronicle of the U.S. Navy’s Space and Space-related Activities, 1944–2009* (revised and updated edition, 2010), available at <https://www.history.navy.mil/research/library/>.

- ²¹ Herbert Friedman, “From the Challenge of World War II to the Frontiers of Space,” *1992 NRL Review* (Washington, DC: Naval Research Laboratory, 1992), p. 24.
- ²² Milton Rosen and Richard Snodgrass, “The High Altitude Sounding Rocket in Upper Atmosphere Rocket Research.”
- ²³ Friedman, “From the Challenge,” p. 24.
- ²⁴ Hevly, *Basic Research*, pp. 137–138; Applied Research Laboratory, *From the Sea to the Stars*, p. 11.
- ²⁵ Applied Research Laboratory, *From the Sea to the Stars*.
- ²⁶ Its initial names were the High Altitude Sounding Rocket (HASR-1 and HASR-2) and the Neptune; see Hevly, *Basic Research*, p. 300, and “The Navy Upper Atmosphere Research Program with Rocket Vehicles, Part 1,” pp. 48–49.
- ²⁷ Homer E. Newell, *Beyond the Atmosphere: Early Years of Space Science* (NASA SP-4211) (Washington, DC: National Aeronautics and Space Administration, 1980), pp. 27–28; Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: National Aeronautics and Space Administration, 2000), pp. 1–2. Available online at <https://history.nasa.gov/SP-4211/cover.htm>.
- ²⁸ <http://www.nap.edu/readingroom/books/biomems/rtousey.html>.
- ²⁹ DeVorkin, *Science with a Vengeance*, p. 81.
- ³⁰ For E. O. Hulburt’s scientific and managerial roles and accomplishments at NRL, see Hevly, *Basic Research*; also see Amato, *Pushing the Horizon*.
- ³¹ This account of Tousey’s rocket-based studies of solar UV radiation borrows heavily from Amato, *Pushing the Horizon*.
- ³² Naval Research Laboratory, *Labstracts*, 75th anniversary pullout section, July 1998; DeVorkin, *Science with a Vengeance*, pp. 197–200.
- ³³ Hevly, *Basic Research*, p. 159.
- ³⁴ Hevly, p. 161.
- ³⁵ Hevly, pp. 165–166.
- ³⁶ Hevly, pp. 166–172.
- ³⁷ Press Release, “Radio Fade-Outs Linked to X-rays from Sun,” National Military Establishment, Department of the Navy, Washington, DC, March 24, 1949.
- ³⁸ Hevly, *Basic Research*, pp. 168–171.
- ³⁹ By 1950, rocket science and upper atmosphere research accounted for over 8 percent of NRL’s research and development budget, amounting to almost \$1,500,000. See Hevly, *Basic Research*, p. 186.
- ⁴⁰ Constance Green and Milton Lomask, *Vanguard: A History* (Washington, DC: National Aeronautics and Space Administration, 1970), p. 9; DeVorkin, *Science with a Vengeance*, p. 185.

4

THE ROCKET SCIENCE CLUB

Even in the first months of 1946, the NRL rocket cadre was looking into the possibility of launching an instrument-laden satellite into orbit. But they reluctantly concluded, according to one historical account of NRL's work in the 1950s, "that engineering techniques were still too unsophisticated to make it practical; for the time being, the Laboratory would gain more by perfecting instruments to be emplaced in and recovered from V-2s."¹ It was during this time—with sounding rockets that went high up and then all the way down, but never into orbit—that Dr. Richard Tousey, Dr. Herbert Friedman, and their respective teams ushered NRL into the rarefied club of space science. They also would ensure that NRL maintained its own bastion of space science and astronomy even as NASA (beginning with its establishment in 1958) and other institutions became national focal points for that new discipline.

It would be another contingent of NRL researchers that set the lab on a related trajectory into space technology.² It was a pathway that, like space-based science, was also dependent upon rockets. But this time NRL would be in on the design and manufacture of the rockets. And immersion in that business would instill at the lab a mind-set that would come to view space as more than just scientifically interesting. At NRL, space would become a new place for its many-faceted engineers to consider furthering military capabilities such as communications, navigation, intelligence-gathering, and perhaps—as booster technology evolved enough to carry many tons of materiel into orbit—even weaponry.

As researchers continued to use the finite supply of V-2s in 1947, and as smaller, less expensive launch vehicles started becoming available—including the Applied Physics Laboratory's Aerobees and Rockoons, a technology championed by University of Iowa astronomer Dr. James Van Allen (formerly of APL) in which a balloon hoists a small rocket about 10 miles into the sky before the rocket then boosts a small payload to higher altitudes—the 90 or so members in the Rocket Sonde Research Section³ were beginning to realize, by necessity, their original ambition to develop their own rocket to take the place of, and to go beyond, the disappearing V-2s.⁴

Originally named Neptune, NRL's V-2 follow-on was dubbed the Viking when the NRL team learned that there already was an aircraft named Neptune.⁵ The Applied Physics Laboratory, under a contract with the Navy's Bureau of Ordnance and the Office of Naval Research,⁶ was developing a modified version of the WAC Corporal.⁷ This was a rocket development project that had its origins within the auspices of Project Hermes, the U.S. Army-initiated rocket and missile project during World War

II.⁸ Although that rocket was to be fin-stabilized and so presumably would provide a better platform for scientific instruments, the NRL team wanted even more performance than that: a rocket with a steering mechanism and gyroscopic control of the rocket's orientation. Such a trait would greatly enhance the ability of instruments on board to keep their optical, X-ray, and other electromagnetic sensors aligned with the sun.⁹

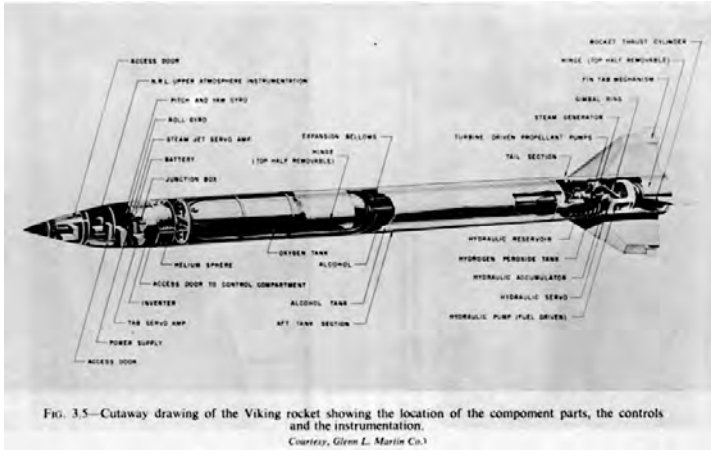
The chief of rocket development on the Viking project was Milton Rosen, whom Ernst Krause had sent to the Jet Propulsion Laboratory (JPL) for an eight-month detail beginning in August 1946 to absorb what he could in one of the nation's bastions of rocket engineering. Only two years earlier, JPL had emerged as a contract-engineering laboratory from a reorganization of the Guggenheim Aeronautical Laboratory of the California Institute of Technology.¹⁰ For Rosen and thereby for NRL, that stint at JPL amounted to a world-class apprenticeship in the art of missile and rocket design, building, and testing.¹¹



Rocket Man. Milton Rosen is shown here as he looked in the 1950s, at a period when the Naval Research Laboratory was getting into the business of rocket design. In 1958, he would transfer to the brand new National Aeronautics and Space Administration. (NRL photo Rosen)

Expanding from specifications that Krause and laboratory leadership had been considering even before the V-2s became available to the Rocket Sonde Research Section, Rosen and NRL coworker Carl Harrison Smith conceptualized the rocket that would become the Viking,¹² though Rosen would become the name most attached to that accomplishment. More than a replacement for the V-2, the Viking would push the art of rocket design; it would have a weight-saving aluminum frame, for example, and a gimballed engine that could guide the vehicle by shunting the thrust gas at different angles. Moreover, the Viking was larger and so could carry heavier payloads than the Aerobees and Rockoons, which had become workhorses of sorts for upper atmosphere research, and take those payloads much higher.¹³

The commercial rocket manufacturing industry was just getting under way, with the primary impetus being design and construction of intermediate and long-range ballistic missiles for delivering nuclear weapons. There were fewer skilled and proven contractors than needed for the approved projects. Out of high-level discussions—involving (1) Krause, (2) the Navy's Office of Research and Invention, or ORI



See-through Viking. Exploded diagram of a Viking rocket, manufactured by the Glenn L. Martin Company in Baltimore, showing the gimballed engine. The diagram dates to 1956. (1956-rocket-diagram-1, <http://libraries.mit.edu/150books/2011/04/12/1956/1956-rocket-diagram-2/>)

(to become, only months later in 1946, the Office of Naval Research, or ONR), (3) Colonel James Bain, who had been charged by Holger Toftoy of the Army Ordnance Department with overseeing interservice activities related to the use of V-2s for scientific research, and (4) other players—emerged a plan. According to a 2007 historical account by two NRL space technologists, “it was one of the most audacious acts in our country’s fledgling space program: NRL’s Milton Rosen and his small branch with four people decided they would have their own rocket built to replace the V-2s.”¹⁴

“After several months of clearing procurement details through channels at the [Navy’s] Bureau of Aeronautics (BuAer), in April 1946, the Chief of Naval Research approved the \$2 million project as a combined NRL, ORI, and BuAer initiative to build 10 high-altitude sounding rockets,” recounted historian David DeVorkin.¹⁵ The task of building the propulsion units went to the New Jersey firm Reaction Motors, Inc. The Glenn L. Martin Company in Baltimore, which had made its name in building aircraft, including the Enola Gay and Bockscar planes that dropped atomic bombs in 1945 on Hiroshima and Nagasaki,¹⁶ won its bid to build the overall Viking rocket. The company’s experience in using lightweight aluminum, which the NRL designers wanted to use for the Viking, helped to make it a company of choice.¹⁷

Rosen was determined that the lab would play a more hands-on role in the design and testing of the vehicle than contractors like Glenn L. Martin were used to. High on his mind was the issue of flight stabilization, for one, which Rosen came to respect due to failures in V-2 firings at White Sands that he knew were due to breakdowns in the stabilization vanes. Also an initial point of contention with Martin was Rosen’s requirement that a prototype of the rocket be subjected to a full static firing test (in which the rocket would be bolted down) to gather reliable data about the thrust and duration of the burn. This step depended on timely delivery of the engine

from Reaction Motors, something that was out of Martin's or NRL's control. And it became a problem. As delivery of the engines slipped several months, Martin engineers proceeded with other tasks, among them designing and building other Viking components and systems. Only in December 1948, almost a year behind schedule, did Martin deliver a fully assembled Viking that was suitable and ready for a full test firing.¹⁸

The NRL and Martin rocket teams, as well as the country's other rocket and missile development teams, were learning just how hard this business was. During static tests, for example, peroxide (a corrosive, oxygen-rich fuel component) leaked repeatedly in the engine's turbine. There also were telemetry failures. These and other difficulties added yet more delays to the original scheduled date for the first launch.¹⁹

That day finally arrived on May 3, 1949. Viking 1, which stood 49 feet tall and weighed nearly 5 tons, lifted off from the flats of White Sands and ascended 80 kilometers. It had soared into the ionosphere. As it approached five minutes into its flight, it was still way short of achieving its hoped-for maximum altitude of 190 kilometers, and it failed to handle intense aerodynamic pressures as it passed back downward from the rarefied ionosphere into the denser atmosphere below. It was torn apart and debris from NRL's first fully made-in-America rocket distributed over an area the size of 10 square kilometers.²⁰

It was a sobering story that Newell—a University of Maryland mathematician-turned-physicist who joined the lab in 1944 and who took over the helm of the Rocket Sonde Research Section from Krause when the latter left for a “crash program” of nuclear weapons testing at Eniwetok Atoll in the Pacific²¹—had to bring to the Upper Atmosphere Rocket Research Panel (UARRP). This panel, with Krause as its head, had been orchestrating V-2-borne research since 1946 (when it was known as the “V-2 Panel”).²² But Newell emphasized the positive, pointing out that just getting the Viking off the ground was an important achievement. He also told the panel that with the lessons learned, later versions of the Viking would feature improved motors that would take the rocket to an altitude of 300 kilometers, deep inside the ionospheric layer, while bearing almost 500 pounds (230 kilograms) of instrumentation.²³

The next two flights, on September 1949 and February 1950, did not reach predicted heights either. But they showed that the gimballed and thereby pointable rocket nozzles provided more stability and control than the V-2 had offered and that the whole Viking system appeared on track to working as planned.

In parallel with the scientific rocket sonde project that Viking represented, the country was in a full-throttle push to develop rockets for IRBMs, or intermediate range ballistic missiles, and ICBMs, intercontinental ballistic missiles. The missile race was on with the Soviet Union, something that the Office of Naval Research was well aware of. Also mindful that there were far more rocket-centric ambitions than there were national resources to support them all, ONR representatives and Newell began touting the Viking program to higher-level military and civilian decision

makers not only as a means for conducting upper atmosphere research but also, as DeVorkin recounted, “as a test vehicle for ballistic missile development.”²⁴

The tack that Rosen and others pushed to render NRL’s Viking program relevant to ICBM development was to suggest modifications to the rocket that would make it valuable to the vexing research problem of developing new super tough materials that could withstand the hellish conditions of heat and friction that an incoming ICBM warhead, still under thrust, would experience as it reentered the atmosphere in the descent phase of its trajectory.²⁵ To do this, the NRL designers came up with a Viking flight test vehicle that could simulate reentry conditions. The crux of the scheme was to stack three rocket stages on top of one another, but use the third stage to accelerate the rocket downward rather than to continue the payload’s upward trajectory. It would be like shooting a bullet down through the ever-thickening atmosphere below from the more rarefied altitudes above. Calculations indicated that the downward kick of the third-stage rocket, in addition to the pull of gravity, would amount to a realistic test for experimental materials designed to withstand reentry from orbit.

It was all part of a gambit to gain favor amidst a competition for national resources, but it carried dangers too. It riled the Air Force and Army, which had their own ballistic missile programs to defend. Representatives from both services contested NRL’s claim of Viking’s relevance to ballistic missile development at the powerful Research and Development Board (RDB) hearings. At the same time, the NRL argument that Viking was furthering the cause of ballistic missiles made it vulnerable to the perception that it, or another missile program, might be redundant and so not worth funding. Consider, for example, that the Viking and an Air Force rocket program, the MX, both featured propulsion systems made by Reaction Motors, both included gimballed thrusters, and both used the same propellants and pressurizing agents.²⁶ Ironically, to gain favor for the MX program, the Air Force argued in early 1949 that its MX-774 rocket, although built with military applications at the fore, could be used for upper atmosphere research too. After all, the conditions in the upper atmosphere had to be understood since they would affect the performance of missiles speeding through it.²⁷

A primary concern for each player in this dynamic was that there was only so much funding to go around. As an advocate for NRL, Newell felt that the RDB, as a top-level decision-making body for the Department of Defense, would favor expending national treasure on military missiles that could also do double duty as carriers of scientific instruments, rather than on rockets such as the Aerobee that were designed exclusively for science. The space scientists at NRL felt they were on their way to getting wedged between hard places. The cost of the big Viking rockets was becoming a concern for laboratory leadership, which strongly approved of the lab’s work in space science but questioned whether the lab should be in the business of rocket building, a heavy engineering lift that could only take financial resources and brain power away from more scientific pursuits.²⁸

Inklings of that tension, recounted DeVorkin, were apparent even as the Viking was under development and testing. “In May 1948, when Newell asked for additional Aerobees and Vikings, his division superintendent, Dr. John M. Miller, shot back, ‘No funds are being specifically budgeted by ONR or NRL’” for upper atmosphere rockets. The budget at the time would buy 10 Vikings and almost certainly a larger number of Aerobees, which had a cheaper per-copy price. All of this implied that the future of the Viking was shaky, but it—among all the major rocket development projects going on—received approval from the Upper Atmosphere Rocket Research Panel. And that helped sway the RDB to keep supporting it too.²⁹

Viking 4, which was launched on the eve of the Korean War on May 12, 1950, stood out as a complete success and then some, because it was fired with high publicity from the deck of a ship, USS *Norton Sound*, as it sailed close to the equator. Although the mission payload was all about upper atmosphere science, the ship-based launch venue was an unmistakable demonstration that American missile technology could be literally shipped near any border in the world. Because of the military relevance of a rocket launch at sea, most of the engineering and technical details of the Viking 4 launch were initially classified.³⁰ Launching from an at-sea platform did make scientific sense too since the structure of the atmosphere varies at different geographic locations and a ship would provide a versatile means of launching from many places. Bearing cosmic ray detectors and pressure and temperature sensors, the vehicle rose to 180 kilometers in a well-behaved trajectory.



High-Profile Launch. Major media reporters were on hand to watch the launch of Viking 4 from the deck of USS *Norton Sound* in 1950. NRL engineers are shown adjusting electronic components for timing solar radiation measurements in the scientific “warhead.” (NRL photo P-238)

The Navy turned to public relations to capitalize on the achievement. It wanted the public to know that it was working hard for the country's defense by developing ways of projecting missile-based defenses farther than ever. Reporters from *Popular Science*, *Time*, *Life*, and other press outlets were invited to witness the Viking launch off of *Norton Sound*. Wrote the *Life* reporter about the Navy's launch: "they had proved for the first time that big rockets, capable of carrying A-bombs several hundred miles, could be launched from the deck of a ship."³¹

With this success in hand, Newell talked up the Viking program to the science-oriented UARRP as well as to the RDB of the Defense Department. As he saw it, a Viking ultimately would reach an altitude of 500 kilometers. That would place it within the so-called F-layer of the ionosphere where no other instrumented rocket had yet been able to go.³² These still were the early years of rocket engineering, of course, so the success of Viking 4 did not guarantee equally good results in subsequent flights. Viking 5 did score another success, bringing a bevy of data-harvesting instruments to a height of about 170 kilometers,³³ but Viking 6 did not fare so well. Its lightweight aluminum fins buckled and collapsed mid-flight, sending the rocket into a crash landing 7 miles from the launch site.³⁴

Even as the Viking program survived harrowing top-level debates—all the way up to the President's office—about duplication and resource allocation, the world continued to turn. In the spring of 1950, as Cold War tensions were building to a war pitch in the Korean Peninsula, the Navy's Bureau of Aeronautics shut down funding for improved Viking rockets, which originally were conceived of in a context of scientific research despite any recasting in a military mold that NRL's rocket cadre had attempted. The nation's and the Navy's priority would have to go with the presidential-level National Security Council's call for rearmament.³⁵

With that budgetary writing on the wall, however, Rosen scrambled to portray the Viking even more in a ballistic missile context. His boss, Radio Division I superintendent John Miller,³⁶ demonstrated his support of this revised way of thinking by creating the Rocket Research Branch in December 1950. The notable absence of "sonde" in the name was an indication that this branch could focus on rocketry and guided-missile work and not so much on the scientific probing that the rockets make possible. In that new institutional context, Rosen and colleague J. Carl Seddon, an ionosphere researcher who had adapted ground-based measuring tools for rocket-based studies,³⁷ prepared a confidential report claiming that it would take little extra investment to leverage the \$3.5 million already spent on the Viking program for the purpose of developing a world-class guided missile. With a radio-controlled guidance system, the Viking could, in DeVorkin's recounting of the report, "deliver a 230 kilogram warhead to a target 240 kilometers away, with an accuracy +/- 450 meters. They also claimed a Viking could be made ready for launch within two hours [of a decision to use one.]"³⁸ War-readiness was an increasingly important concern as the Cold War heated up.

It was a tough sell, though, and in the end, the Bureau of Aeronautics declined to commit the \$2.5 million that NRL proposed it would need to build a half-dozen of the modified Vikings. Stacking the deck against NRL too was that the Navy as a whole at this time also had its eyes on a competing BuAer missile program, the submarine-launched Regulus. And the Applied Physics Laboratory soon would enter its own contender, the Triton. There was plenty of competition for a finite amount of funding and resources. The rejection of the NRL program by BuAer, the primary sponsor of the lab's rocket work, meant that the Viking's days were numbered. Viking 7 was the last of the first-generation Vikings. It went up a minute shy of 1:00 a.m. on August 7, 1951. And its engine burned one second longer than was needed to break the altitude record for a single-stage rocket. Rosen and his Viking project colleagues had wide eyes as the rocket continued to coast higher and higher. Its ascent ended at 217 kilometers, shattering the previous record of 182 kilometers set by a V-2 launched nearby almost five years earlier. Only this time, the rocket that held the record was conceived of, designed, and built in the United States of America under the direction of NRL.³⁹

The next three Vikings under the original contract with the Glenn L. Martin Company would be fatter and heavier, a slight sacrifice in aesthetics for the hope of attaining higher altitudes. They would demonstrate, however, that rockets still rose on a mixture of thrust and a prayer.⁴⁰ This new Viking series started out ominously on June 6, 1952, when the Viking 8 rocket ripped from its tie-down blocks during a test firing of its motor and then crashed in the desert about 4 miles southeast of the launch site. The next Viking fared better. Even so, its engine stopped earlier than expected, lofting the rocket to a height of about 216 kilometers, or about 80 kilometers shy of its intended peak. During the up and down round trip, onboard instruments enabled NRL researchers to make, among other things, solar radiation and cosmic ray measurements.

The June 30 firing of Viking 10 turned harrowing when the rocket's tail section exploded, setting off a fire. Despite the unintended pyrotechnics, no one was hurt. Workers were even able to quash the fire soon enough to salvage much of the rocket. The rocket was rebuilt and, like Lazarus coming back from death, the reconstructed Viking 10 soared upward from White Sands on May 7, 1954, to a record-equaling height of 217 kilometers. It provided the first measurements ever of positively charged ions in the ionosphere at that altitude.⁴¹

In between the death and resurrection of Viking 10, NRL awarded the Glenn L. Martin Company another contract for four more Vikings. Viking 11, launched only two weeks after Viking 10, surpassed the performance of its predecessors, taking the altitude record to 158 miles, or more than 250 kilometers. What's more, NRL scientists were able to retrieve the armored steel film cassette from an aerial camera that survived the rocket's crash landing. In it was a cache of spectacular high-altitude portraits of the Earth, revealing magnificent cloud formations and global weather

patterns. The then-novel pictures ran in many newspapers and magazines, thereby associating NRL in the public eye with the nascent rocket age.



The Lazarus Viking. In a hangar at the White Sands Missile Range in New Mexico, NRL engineers conduct an instrument check on Viking 10. On the first launch attempt on June 20, 1953, the engine exploded, but the rocket was subsequently rebuilt and successfully launched on May 7, 1954. It reached an altitude of 136 miles (217 kilometers). Shown also is the scroll of telemeter data from the flight. (NRL photos 53-061582(22) and 54-061582(17))

Viking 11 also carried innovative detectors that recorded emissions due to cosmic rays (an interest that old-timer and NRL's early rocket champion, E. O. Hulburt, had brought into the lab and then handed off to others including Herbert Friedman) and telemetered the data down to Friedman and his colleagues.⁴² Viking 12's February 4, 1955, launch did not live up to the building expectations that came with Viking 11. But its camera produced some of the best high-altitude pictures of Earth that yet had been taken.

As exciting as all the Viking firings were, they were expensive by the standards of the day, on the order of \$400,000 per shot. And the scientists who had spent many

months designing experiments or equipment to fly on the rockets never quite knew what to expect. There never were guarantees that their rocket program would last long. For one thing, smaller, more reliable rockets like the Aerobees and WAC Corporals would become the go-to vehicles for studies in which the flights lasted only a few minutes. Also at play were policy debates, like those within the RDB about allotting funds and human resources to scientifically driven rocket development and production if military and national security requirements ought to take precedence.



Lofty View. Among the last of NRL's Viking series to launch, Viking 12 reached an altitude of 143 miles (230 kilometers). During its parabolic trajectory, an onboard camera snapped this picture of the planet below. (NRL photo 60578(35))

There also was something unique about NRL's funding that would prove both disadvantageous and advantageous at different times and in different national and geopolitical contexts. Here's how a team of two historians, who examined NRL's early rocket research and achievements in a NASA-funded historical analysis, characterized the situation:

"NRL had been founded in 1923, but a post-World-War-II reorganization within the Navy had brought the Office of Naval Research into being and given it administrative control of the Laboratory's finances. ONR allotted the Laboratory a modest fixed sum annually, but other Navy bureaus and federal agencies frequently engaged the Laboratory's talents and paid for particular jobs. The arrangement resembled that of a man who receives a small retainer from his employer but depends for most of his livelihood on fees paid him by his own clientele for special services. NRL's every contract, whether for design studies or hardware, had to be negotiated and administered either by ONR or by one of the permanent Navy bureau[s],"⁴³ such as the Bureau of Aeronautics.

This funding reality—which essentially remains in place today and means the lab operates by way of a “working capital fund” protocol that largely decouples its research portfolio decisions from year-to-year Congressional budget appropriations—meant the nearly decade-long program of research that NRL had conducted with big rockets since Krause secured access for the lab to captured V-2s in 1946 always was at high risk. But in 1955 there still were two more Vikings left in the extended contract with Martin. Rather than getting dubbed Viking 13 and 14, they would become known as TV-0 and TV-1, where the TV stands for test vehicle, a designation that would prove to be painfully ironic. These Vikings-turned-test-vehicles would become central parts of a national goal to go beyond the short flights of sounding rockets designed to take measuring instruments for a once-only, up-and-down excursion and rather to place artificial satellites into orbits that would repeatedly circle the Earth over extended periods of time. The program to do so became known as Project Vanguard.

Talk of such world-circling spacecraft had been going on in a variety of circles for many years, and most vociferously in the 1950s within the Air Force, which had viewed itself as the natural federal locus of any U.S. space program.⁴⁴ The new effort became a sensational highlight and headliner of an ambitious scientific initiative, called the International Geophysical Year, which ultimately would involve 67 countries, to study the Earth as a whole from the land, sea, sky, and—everyone hoped—from space.⁴⁵ The launch of what originally had been designated TV-3 would become a pivotal event in the history of the Naval Research Laboratory and the U.S. space program.

¹ Constance Green and Milton Lomask, *Vanguard: A History* (Washington, DC: National Aeronautics and Space Administration, 1970). Available online at <http://history.nasa.gov/SP-4202/toc2.html>.

² Homer E. Newell, *Beyond the Atmosphere: Early Years of Space Science* (NASA SP-4211) (Washington, DC: National Aeronautics and Space Administration, 1980), pp. ix–x.

³ David H. DeVorkin, *Science with a Vengeance: How the Military Created the U.S. Space Sciences after World War II* (New York: Springer-Verlag, 1992), p. 73.

⁴ Naval Research Laboratory, “The Navy Upper Atmosphere Research Program with Rocket Vehicles, Part 1,” Washington, DC, April 10, 1947, pp. 7–9, 49–58.

⁵ Green and Lomask, *Vanguard*; Milton Rosen, *The Viking Rocket Story* (New York: Harper & Bros., 1955); Homer Newell, oral history conducted by Richard F. Hirsh in Wintergreen, Virginia, July 17, 1980, Niels Bohr Library and Archives, American Institute of Physics, College Park, MD, http://www.aip.org/history/ohilist/4795_1.html.

⁶ The Office of Naval Research was established in 1946 out of the Navy’s short-lived Office of Research and Inventions, which was established at the end of World War II. ONR became a model for the civilian sector National Science Foundation, which was established in 1950 to further basic research at U.S. universities.

⁷ See, for example, <http://www.boeing.com/boeing/history/mdc/wac.page>, a Boeing history web page.

⁸ DeVorkin, *Science with a Vengeance*, pp. 47, 168–171.

- ⁹ Green and Lomask, *Vanguard*.
- ¹⁰ DeVorkin, *Science with a Vengeance*, p. 169.
- ¹¹ DeVorkin, p. 175.
- ¹² DeVorkin, p. 175.
- ¹³ Rosen, *The Viking Rocket Story*; M.W. Rosen and J.M. Bridger, "Rocket Research Report No. 1 —The Viking No. 1 Firings," NRL Report 3583, 1949, pp. 49–58.
- ¹⁴ P.W. Binning and J.W. Middour, "A Brief History of NRL's Early Firsts in Spaceflight," *Advances In Astronautical Sciences* 129 (2008): 1233–1250.
- ¹⁵ DeVorkin, *Science with a Vengeance*, p. 175.
- ¹⁶ http://www.marylandaviationmuseum.org/history/martin_aircraft/index.html.
- ¹⁷ Binning and Middour, "A Brief History."
- ¹⁸ DeVorkin, *Science with a Vengeance*, pp. 175–177.
- ¹⁹ DeVorkin, pp. 175–177.
- ²⁰ DeVorkin, p. 176.
- ²¹ DeVorkin, p. 167; see Ernst Krause obituary in the *New York Times*: <http://www.nytimes.com/1989/08/29/obituaries/ernst-h-krause-76-aerospace-executive.html>.
- ²² DeVorkin, *Science with a Vengeance*, p. 168.
- ²³ DeVorkin, p. 176.
- ²⁴ DeVorkin, pp. 177–184.
- ²⁵ Binning and Middour, "A Brief History," see ref. 20.
- ²⁶ DeVorkin, *Science with a Vengeance*, p. 178.
- ²⁷ DeVorkin, p. 179.
- ²⁸ DeVorkin, p. 179.
- ²⁹ DeVorkin, pp. 178–180.
- ³⁰ DeVorkin, p. 177.
- ³¹ DeVorkin, p. 181.
- ³² On February 24, 1949, a Bumper WAC Corporal, a two-stage rocket built in a project of the Jet Propulsion Laboratory and Wernher von Braun's rocket team with the Army, reached a record altitude of 250 miles, but it did not carry scientific instruments. It was the first rocket to reach outer space and featured a JPL WAC Corporal rocket atop a V-2. The head of JPL would later suggest this launch could mark the beginning of the space age; see S. Starr, "The Launch of Bumper 8 from the Cape, The End of an Era and the Beginning of Another," paper associated with a talk given at the 52nd International Astronautical Congress 1–5 October 2001, Toulouse, France.
- ³³ Bruce Hevly, *Basic Research Within a Military Context: The Naval Research Laboratory and the Foundations of Extreme Ultraviolet and X-ray Astronomy, 1923–1960* (Baltimore, MD: Johns Hopkins University, 1987), pp. 207–208.
- ³⁴ Ivan Amato, *Pushing the Horizon: Seventy-Five Years of High Stakes Research and Technology at the Naval Research Laboratory* (Washington, DC: Naval Research Laboratory, 1998), Chapter 8; a summary of Viking flights 5 through 12 appears in *Space Frontiers* 2(2), (May-June 1986): 3–20.
- ³⁵ DeVorkin, *Science with a Vengeance*, p. 180.
- ³⁶ http://en.goldenmap.com/John_Milton_Miller.
- ³⁷ Newell, *Beyond the Atmosphere*, pp. 76, 78.
- ³⁸ DeVorkin, *Science with a Vengeance*, p. 181.
- ³⁹ Amato, *Pushing the Horizon*, Chapter 8.
- ⁴⁰ The Viking story has been told repeatedly. See, for one, Rosen, *The Viking Rocket Story*.
- ⁴¹ Green and Lomask, *Vanguard*.
- ⁴² Herbert Friedman, "Reminiscences of 30 Years of Space Research" (Washington, DC: Naval Research Laboratory, August 1977).
- ⁴³ Green and Lomask, *Vanguard*.
- ⁴⁴ One of the most influential reports that paved the way for an era of satellites was titled "Preliminary Design of an Experimental World-Circling Spaceship." It was published in May

1946 under a government contract and program, Project RAND, by an engineering unit of the Douglas Aircraft Company in Santa Monica, CA. The organization created for Project RAND would evolve in 1948 into the nonprofit think tank, the RAND Corporation.

⁴⁵ Green and Lomask, *Vanguard*.

5

TRANSCENDING THE ATMOSPHERE: PROJECT VANGUARD

In the summer of 1954, during early planning for the International Geophysical Year (IGY)—which would last 18 months, from July 1, 1957, to December 31, 1958—the trajectory of big-rocket development for science at the Naval Research Laboratory would take a turn upward. Suddenly, a top-priority scientific basis for rocket development, ostensibly divorced from any military basis, swooped into the national agenda in a way that would keep NRL in the rocket business. Members of the International Scientific Radio Union, one of the organizations that built momentum for the IGY in the early 1950s, recommended an idea that had been percolating in both classified and open rocketry circles: that the IGY planners consider the ambitious though plausible idea of going beyond sounding rockets, like the Viking, Aerobee, and WAC Corporal, to designing and launching artificial world-circling satellites as platforms for research.¹

The call for such technology launched the collective imagination of the IGY community into orbit with a sense that the time finally was ripe for crossing over the line from fiction to reality. Later in 1954, the U.S. National Committee (USNC) for the 67-nation IGY set up advisory groups to study the feasibility of launching a satellite sometime during the IGY time frame and to determine whether a satellite would genuinely be a boost for research. To no one's surprise, the answers were yes and yes. With the nods of advisory bodies, the USNC proceeded in 1955 to draw up plans for a satellite program.

On July 29, 1955, the White House publicly announced jointly with the Belgium-based Special Committee for the International Geophysical Year (IGY's international headquarters) that the United States intended to launch "small unmanned earth-circling satellites" as part of the IGY. "This program will for the first time in history enable scientists throughout the world to make sustained observations in the regions beyond the atmosphere," President Eisenhower's press secretary, James Hagerty, told reporters at the White House.²

The timing of the announcement was in part due to fears that the Soviet Union would snatch the glorious moment.³ Four days later, as it turned out, Moscow announced that the Soviet Union would place its own satellite in orbit during the IGY. Though national leadership did not portray the promised satellite launches as a technology race, it was just that to many of those involved, and the world-startling



Stamp of Approval. A 3-cent U.S. postage stamp in 1957 marks the country's involvement in the International Geophysical Year, an earth science collaboration among 67 countries.

result of the dueling programs in 1957 would retroactively enlarge the dual efforts to build a scientific satellite into a race for international prestige and global technological predominance.⁴

As historians Constance Green and Milton Lomask have pointed out, those in rocket circles knew the Soviet authorities had been promoting space exploration to the country's citizenry. "As everyone present knew," the historians observed, "A.N. Nesmeyanov of the Soviet Academy of Sciences had said in November 1953 that satellite launchings and moon shots were already feasible; and with Tsiolkovsky's work now recognized by Western physicists, the Americans had reason to believe in Russian scientific and technological capabilities. In March 1954 Moscow Radio had exhorted Soviet youth to prepare for space exploration, and in April the Moscow Air Club had announced that studies in interplanetary flight were beginning."⁵

Despite all the rhetoric, when the U.S. and U.S.S.R. made their dual announcements for plans to put satellites into orbit, no one knew exactly how it could be done. No rocket on Earth could do it. Only two groups of U.S. rocketeers, within the Army and NRL, respectively, were serious contenders for taking on the responsibility. At the time of Hagerty's White House announcement, a high-level committee, the Stewart Committee, directed by rocketeer Homer Stewart of the Jet Propulsion Laboratory at the California Institute of Technology, was convened at the behest of Assistant Secretary of Defense Donald Quarles. The committee's charge was to decide which U.S. rocket engineering team would get the once-in-history shot at being the first to put an artificial satellite into Earth orbit.

The Air Force considered itself a natural contender but its development work on the Atlas rocket, which was slated to become the launch vehicle for ICBMs, by law had to take precedence over a scientific rocket project. That left two tight-knit and proud groups of rocket designers—one at NRL under Milton Rosen and Dr. Homer Newell, and one at the Army's Redstone Arsenal in Huntsville, Alabama, under Dr. Wernher von Braun, the high-profile German rocketeer behind the V-2s whom the

U.S. Army, much to the Soviet Union's chagrin, had "acquired" for its own rocket and missile ambitions after the war. The Army proposal rested mostly on the strength of the booster component and actually included NRL-developed telemetry and satellite tracking components.⁶ Von Braun would become an iconic figure in the U.S. civilian space program when it would begin to organize later in the decade.

The Army proposed that the nation go with its satellite, dubbed the Orbiter, some of whose components already had been under development with funds from the Office of Naval Research.⁷ It called for a multistage rocket that could put a 5-pound satellite into orbit. NRL's proposal was for a three-stage rocket using a Viking-based design and an Aerobee-based design for the first and second stages, respectively, and a newly designed, yet-to-be-tested upper stage. Rather than a tiny 5-pound payload, however, the NRL proposal called for a 40-pound payload of scientific instrumentation. NRL also had in hand a workable plan for a radar tracking system, called Minitrack, which NRL researchers John Mengel and Roger Easton had developed to track Viking trajectories. Minitrack began a technology lineage that would lead to today's systems that track satellites and orbital debris. This was a big advantage for NRL since the challenge of finding and tracking a 5-pound or 40-pound satellite in the vast orbital expanses around the planet mocked the trouble of finding a needle in a haystack.

The Stewart Committee assessed the pros and cons of each proposal and sent its recommendation to the Secretary of Defense in early August 1955. The committee's vote was close and controversial. For one thing, note NRL space systems scientists Jay Middour and Patrick Binning in a historical account of NRL's early space efforts, "one member of the committee was unable to attend the formal vote. At the vote, three members supported the NRL proposal, two members supported the Orbiter proposal, and the remaining two members sided with the majority explaining that they were not guided-missile experts. The outcome might have been different had the absent member voted for the Orbiter proposal, as it [was] rumored he would."⁸ So it was by the slimmest of a majority that the Stewart Committee favored NRL's proposal over the Army's.

It took another head-to-head round involving detailed reports and testimonials by generals, scientists, engineers, and company executives before the Stewart Committee made its final decision. According to a NASA analysis, the Army proposal was stronger on the booster side, but its proposal of a small, poorly instrumented satellite was a far cry from the instrument-laden Vanguard satellite that NRL was proposing.⁹

In September, it became official. NRL had won stewardship of the satellite program, which became known as Project Vanguard. NRL would never be the same. In typical government fashion, Middour and Binning point out, "NRL was not notified of its selection for two months [after the Stewart Committee's recommendation in August]. On September 9, 1955, the Deputy Secretary of Defense, Reuben Robertson, formally notified the Secretaries of the Army, Navy, and Air Force that the Navy was in charge of the tri-service program. Then, the Secretary of the Navy waited more

than two weeks, until September 27, 1955, to formally designate the Office of Naval Research as Administrator. Two more weeks, a full two months after the recommendation was made, on October 6, 1955, the Chief of Naval Research officially notified NRL that it was to take charge.”¹⁰

The objective of Project Vanguard was far-reaching, nothing less than to design, build, and launch a three-stage booster system, six test vehicles, and another half-dozen mission vehicles with the ultimate goal of delivering an instrument-equipped IGY satellite into orbit where it could make measurements of geophysical relevance. The booster would feature first and second stages that already had proven themselves and a new third stage that according to the project’s director, Dr. John Hagen, “would be, when built, a real advance in solid-fuel rocket technology.”¹¹ Given the well-known rate of failure in the rocket business, the Vanguard team’s stated metric of success went like this: at least one of the mission rockets should make it into orbit; the team would track and verify its orbital path; and the satellite would accomplish at least one scientific experiment, all before the end of the IGY.¹²

As is apparent in once-classified documents from the National Security Council, the science-centered Project Vanguard was part of a geopolitical agenda for President Eisenhower and the national security community. By launching a scientific satellite during the IGY, the U.S. would be able to establish a legal “open skies” precedent by which the jurisdiction of sovereign states over their own air space would not extend to outer space. With a “freedom of space” definition established, it then would be quite legal to fly surveillance satellites directly over Soviet territory.¹³ Of course, this same freedom would give the Soviet Union license to fly spacecraft over U.S. territory. Even if Project Vanguard scientists were serving a second duty of influencing global space policy without deliberately doing so, the scientific opportunities in satellites remained as exciting as they possibly could get. “Recognizing that the project was of a magnitude greater than that for which a division was geared to handle and that the successful development of the project would call for talents from many divisions in the Laboratory, NRL’s Commanding Officer, Capt. Samuel Tucker, and the civilian Director of Research, Dr. E. O. Hulburt, decided to form a group outside the division structure to carry out the project,” recalled Hagen, superintendent of the Atmosphere and Astrophysics Division and the man who was chosen as Director of Project Vanguard.¹⁴ *Life* magazine would later describe Hagen’s experience in Project Vanguard as “one of the most trying ordeals ever imposed on an American scientist in the course of his work.”¹⁵

Hagen had three years to pull off the task, which required as much administrative orchestration as technical innovation. The Vanguard team organized into groups devoted to designing the rocket, designing the satellite, miniaturizing instruments and telemetering equipment so they could fit into the satellite, developing orbital calculations and computerized means of handling the payload, and building a global rocket and satellite tracking system. Scheduling, budgeting, and liaison with other

parts of the Defense Department also fell under the aegis of Hagen and the Vanguard team. Moreover, the team had to work closely with the Glenn L. Martin Company, the prime contractor on Viking and now with the Vanguard project, to build the first stage and to assemble the completed vehicle with the second and third stages and other components coming in from other contractors.

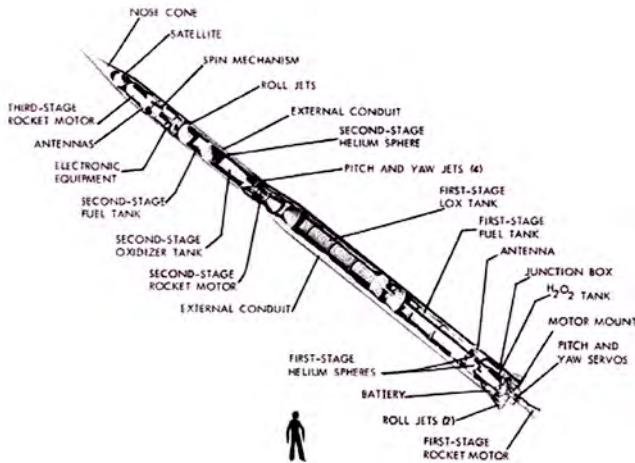


Play Ball. Project Vanguard director Dr. John Hagen holds a model of the satellite that would be placed in orbit and make measurements of solar energy, temperature, and other geophysically relevant phenomena. (NRL photo 255-PV-VAN-1731 DR HAGEN WITH SAT MODEL.jpg)

The first-stage engines and pumps, which formed the heart of what essentially were modified Viking rockets fueled with kerosene and liquid oxygen, came from General Electric, for example. In the company's design, the breakdown of another liquid, hydrogen peroxide, produced superheated steam and a flow of oxygen that powered the turbine-driven fuel and oxidizer pumps, while inert helium gas pressurized the fuel tanks.¹⁶ The Aerojet General Company, the firm that built the Aerobee rockets, was contracted to supply the liquid-fueled second-stage rockets, incorporating a guidance package supplied by the Minneapolis-based Honeywell Company.¹⁷ The technology-pushing, solid-fuel third stage, which would take the Vanguard satellite into orbit from the high perch that the previous two stages had achieved, had its own set of contractors. Most notable among them was the Grand Central Rocket Company and Allegheny Ballistics Laboratory, whose novel proposal featured a weight-saving Fiberglas casing instead of metal.¹⁸ Also pitching in were research and technology organizations such as IBM, Caltech's Jet Propulsion Laboratory, and the Bendix Corporation (which would later become Allied Signal), which was contracted, in Hagen's words, for "the construction and installation of the tracking devices which were developed under the name 'Minitrack.'"¹⁹

Equally as challenging as organizing the construction of the rockets was the job of securing and preparing a launch site. For a multi-stage rocket whose second stage would drop from the sky as far away as 1,500 miles from the launch site, the familiar White Sands missile site was too close to populated areas. With its over-ocean launches, Cape Canaveral on the Florida coast was the logical choice. But when the Vanguard team approached the Army with a request to share the launchpad associated

with von Braun's Redstone missile, the team was quickly turned down, Hagen wrote, "on the basis that any interference with the Redstone program would be harmful to the U.S. ballistic missile program,"²⁰ a defense program that had higher national priority than an IGY scientific program.



Vanguard Revealed. A rough exploded view of the Vanguard rocket design shows the small spherical satellite at the top of the three-stage booster. (*Vanguard_rocket_cutaway_view*)

"In the end, because the Air Force and Army claimed full occupation of launch facilities and since Vanguard had no military priority, we were forced to build our own hangar, blockhouse, and launch stand," Hagen recounted. "All the while, the Scientific Program group worked with the committee for the IGY of the National Academy of Sciences to select a series of experiments from scientists around the country and then to work with those scientists in preparing the experiments so that they would stand the rigors of launching and flight."²¹ It was a nonstop orchestration of thousands of people distributed across the country working on scores of projects at a cost ultimately of over \$100 million.²²

The first sign of difficulty in the program came early after NRL had signed a letter of intent with the Glenn L. Martin Company. Unknown to NRL, the company previously had also been selected as the prime contractor for a top-priority Air Force project to develop the Titan, a second-generation intercontinental ballistic missile. Many of the top-flight Martin engineers who had worked on NRL's Viking rockets were now assigned to the higher-priority Titan project. That left Project Vanguard with a less experienced Martin crew.

The original plan was to progress toward a series of six satellite launch attempts but not before working out the engineering kinks with a set of six test vehicles, designated TV-0 through TV-5. The first tests would use up the two leftover Viking rockets and check out new telemetry hardware, as well as the new third stage. TV-2 would be the first test of a newly designed first stage, which essentially was a Viking with a

more powerful engine. TV-3 would be the first full test of the three-stage design. Assuming enough information about the rocket's performance had been gleaned from the prior tests, TV-4 would shed some of the rocket testing and diagnostic instrumentation and telemetry. That would open the way for the final test vehicle, TV-5, which would use up the sixth and final test booster and would include a dummy satellite in its payload bay. Following TV-5 would then come the six satellite-launching vehicles (SLVs), each of which could carry a 20-inch sphere with an IGY payload.²³

Tracking the satellite was a central part of the plan and John Mengel, whom Hagen named to head the Tracking and Guidance Branch for Project Vanguard, would be most responsible for that task. It was a role he would continue later at NASA when the country's civilian space program began operating in October 1958. Mengel started his NRL career in 1946 with work on submarine detection and tracking. Later, in the Rocket Sonde Research Section, he developed expertise in radio control systems and was a natural choice to head Project Vanguard's Tracking and Guidance Branch. Helping him get the tracking component of Project Vanguard up and running was Roger Easton, destined to become a hall-of-famer in the history of navigation technology as a central figure in the development of the modern-day Global Positioning System (GPS).

Because their professional home was one of the country's premier bastions of expertise in radio and other invisible swaths of the electromagnetic spectrum, the NRL approach to tracking would piggyback on the lab's more than 30 years of work in radio tracking and ranging, that is, radar. Tracking spacecraft was a brand new game, however, so IGY leadership hedged its bets by also supporting "optical tracking" based on high-power, ground-based telescopes. For that tracking tack, the National Academy of Sciences gave the Smithsonian Astronomical Observatory (SAO) \$3,380,000 to build a worldwide network of Baker-Nunn telescopes. These instruments presumably could determine a satellite's swiftly moving position by comparing it with the locations of stars behind it, relying on a photographic system attached to the telescope to capture the lights in the night sky on film.²⁴

Within a few years, SAO had set up a dozen optical stations on every continent except Antarctica. These stations were distributed over a wide swath of latitudes, ranging about 40 degrees north and south of the equator. The scale and audacity of the network matched the scale and audacity of deploying the Vanguard satellites, but the optical tracking technique suffered from what was known as the acquisition problem. In short, it was extremely difficult to find the object to track in the first place, especially one that was merely several feet across or less and flying hundreds of miles overhead at many thousands of miles per hour. Moreover, the weather had to be good with not too much cloud cover. And for any particular optical station, the lighting had to be just right: just before sunrise or sunset when the sun would illuminate the satellite against a dark background. The champions of the system demonstrated it could work, but its drawbacks were impossible to ignore.

Because of the “acquisition problem,” Rosen, one of the Vanguard program’s leaders at NRL, was adamant that an optical approach would not work with satellites. So he asked Dr. Richard Tousey, one of his in-house optics experts who had embraced the V-2s and Vikings for his studies of the solar spectrum of UV and X-ray radiation in the upper atmosphere, to look into the practicalities of the approach. Tousey found that it indeed would be possible for a camera to detect a small Vanguard satellite. But there was a catch: Tousey calculated that it would be immensely unlikely that the camera would be able to find the satellite at all, unless, that is, the operator of the camera system already knew where to look. It was a paradox: you could track a satellite optically if you already knew where it was and where to look, but then why would you need an optical tracking system? In Tousey’s opinion, wrote Sunny Tsiao, a scholar who has chronicled the history of satellite tracking, “the probability of successful optical acquisition of a Vanguard-sized satellite on the first visual pass was only 1×10^{-6} , that is, literally one in a million.”²⁵

This is where radar and hence NRL come prominently into the Vanguard tracking story, and from there even into today’s tracking of many thousands of manmade orbiting objects. With its roots in the 1920s, radar had become in the 1940s an enormously consequential technology that influenced the outcome of World War II. The world’s military powers and technologically advanced nations would also put radar to use on their way toward the Space Age. As the Army ramped up its missile development work and testing at White Sands in New Mexico, it turned more and more to radar tracking instead of optical tracking. Part of the incentive for this shift was that the radar data was in electronic form from stem to stern and bypassed any need for transforming raw optical, photographic, or other analog forms of data into electronic forms, perhaps by way of paper punch cards that a computer could read. The all-electronic advantage of radar made the tracking data amenable not only to computer analysis and trajectory calculations (even with the vacuum-tube-based electronic computers of the 1950s), but also to networking across tracking stations, to command and control signaling, and to telemetry.²⁶

Among the first radar tracking systems was one built by the Radio Corporation of America (RCA). It featured mobile units powered either by commercial power sources or by generators if deployed to underdeveloped sites. These were linked into a network “to transmit data to a control center where consoles displayed information on the radar returns for the test engineers,” according to Tsiao.²⁷

Mengel, Easton, and colleagues at NRL had built and tested at White Sands what proved to be an even more capable radio-based system for tracking ballistic missiles. Built for use in the Viking rocket program, it relied on an interferometric principle in which a radio signal originating from a flying or orbiting object (either from a transmitter or in the form of a reflection of a probe signal) would reach two receivers at ever so slightly different times.²⁸ That time difference entailed that the waves likely would arrive at the two receivers with a difference in their phases. A comparison of

the phases of these received signals, together with knowledge of the precise distance between the receivers, and the well-known speed of light, was sufficient for calculating the angle from the receivers at which the object was situated when it emitted or reflected the signal.

Several such measurements over a period of time from one pair of antennas, or from sequences of well-positioned pairs of antennas, would enable NRL trackers to determine an object's trajectory, which in the case of a satellite would amount to an orbital trajectory. "This technique had the advantage of yielding highly accurate tracking angles and could be used under virtually any atmospheric condition," noted Tsiao.²⁹

So Rosen turned to Mengel and his staff in the Tracking and Guidance Branch to come up with a practical alternative to the optical tracking techniques that most were still betting on. What was foremost on these radio engineers' minds was the need to keep their transmitting system small and lightweight. It would have to be placed on a satellite, which would weigh in its entirety only a few pounds. What Mengel's team came up with on short order was a transmitter that weighed in at 13 ounces.

Mengel's name for the system, Minitrack, short for "minimum-sized tracking system," relied on a transmitter as miniaturized as possible while still being able to transmit signals to antenna pairs at a ground station. The resulting Minitrack oscillator was quartz-crystal-controlled and fully transistorized, which was still novel at the time. The battery-powered transmitter had a 10-milliwatt output, operated on a fixed frequency of 108 megacycles (megahertz), and had a predicted lifetime of 10 to 14 days.³⁰

"What apparently had sold the Defense Department on our proposal was the fact that it consisted of a good radio system which would be infallible in picking up the satellite in orbit," explained Mengel, referring to the choice between NRL's and the Army's proposal for orchestrating the nation's promise to orbit a scientific satellite for the IGY. This pioneering global tracking system, which required the construction of a worldwide network of stations, was to become operational in 1957 at a cost of \$13 million.³¹

Getting the IGY's community of scientists to become confident in new radar tracking concepts over optical tracking techniques was a hard sell. Toward that end, by way of technical papers and talks, Mengel and his team, most notably NRL's Roger Easton and Dr. Paul Herget, who was director of the Cincinnati Observatory and a consultant for Project Vanguard, fleshed out the daunting tracking challenges and stunning capabilities of the Minitrack system. On one occasion in front of a group of scientists and engineers, Mengel described the tracking feat required for Project Vanguard this way: "Let a jet plane pass overhead at 60,000 feet at the speed of sound, let the pilot eject a golf ball, and now let the plane vanish. The apparent size and speed of this golf ball will closely approximate the size and speed of a satellite 3 feet in diameter, at a height of 300 miles."³²



Minitrack Footprint. A pivotal component of Project Vanguard, the satellite-tracking system called Minitrack would become the prototype of the nation's primary satellite tracking system, NAVSPASUR, in the early years of the Space Age. This 1956 photo shows the primary site of the Minitrack system in Blossom Point, Maryland. (NRL photo 56-045950.jpg)

With a series of receiving stations separated every 500 or 600 miles in a north-south line from rural Blossom Point, Maryland—which would become a prominent and long-lived outpost about 45 minutes from NRL for all subsequent generations of NRL space technologies—through the southern states and Central and South America all the way south to Santiago, Chile, the researchers designed a “radio fence” that could track Vanguard satellites. Additional Minitrack stations went up in Australia and South Africa. The prototype station, at the Naval Electronics Laboratory (NEL) in San Diego, which was not positioned to track Vanguard satellites, would be, in early October 1957, among the first stations to verify that the Space Age had begun when the Soviet Union launched Sputnik 1.

With launches slated to go from the Florida coast and tracking stations set up around the world, the Vanguard team established a control center at NRL with teletype connections to all relevant locations. Among these was a link to the Vanguard Computing Center, which was situated at 615 Pennsylvania Avenue NW in Washington, DC (about one mile from the White House) and equipped with a state-of-the-art IBM 704 computer for orbital computations.³³

The space vehicle and ground pieces of the Vanguard project were coming together. By the spring of 1957, the first two test launches, TV-0 and TV-1, had together demonstrated that the telemetry and tracking systems worked. They also had shown that a third stage indeed could be ignited in the near vacuum of the upper atmosphere, a must-happen event that no one knew was actually possible. As all rocketeers

knew from experience, nothing could be taken for granted in this fetal stage of the Space Age.³⁴



Vanguard Downtown. Located at 615 Pennsylvania Avenue NW, not far from the White House, was the storefront Vanguard Computing Center where the trajectories of Vanguard satellites were computed from signals picked up by the Minitrack station in Blossom Point, Maryland, and associated stations elsewhere. (NRL photos 255-PV-VAN-1172 VANGUARD COMPUTING CTR 1.jpg and 255-PV-VAN-1168 VANGUARD COMPUTING CTR 2.jpg)

Then, with TV-2—that is, test vehicle number 2—installed on the launch pad, the Vanguard team and the rest of the world heard on October 4, 1957, a revelation that could not have been more shocking. The morning started out for Hagen at an IGY meeting in Washington on missiles and rockets. At the meeting, Hagen had sought out Sergei Poloskov, a Russian rocket expert who was in attendance. “Hagen asked if the U.S. would be given time to change its radio tracking equipment should the Russians soon launch a satellite,” according to a *Life* magazine article published the following March about what would become Hagen’s rough ride as director of Project Vanguard. “Poloskov smiled and said plenty of notice would be given.”³⁵

That evening, Hagen skipped a cocktail party at the Russian embassy and returned to his home in Arlington, Virginia. There, his 16-year-old son Peter told him what he had just learned from a phone call he had taken at the house: the Russians had launched the world’s first artificial satellite—Sputnik. The senior Hagen was stunned.

Friedman, who soon would become NRL’s premier and most publicly visible astronomer, recalled the immediate aftermath: “Public reaction was initially mild, reflecting President Eisenhower’s comment that ‘it does not raise my apprehension one iota about national security.’ The numbness wore off quickly, and public figures began to decry the shameful situation with the usual accusations of administration penny-pinching, shortsightedness, lack of vision, and general stupidity. Truman blamed the McCarthy era for having deprived America of its best brains. By implication the Vanguard team was a bunch of second-raters. The Senate Preparedness Committee chaired by Lyndon Johnson immediately began an inquiry into the status of U.S. rocket and satellite programs.”³⁶

Scooped and embarrassed, Hagen and the Vanguard team had to push on. They successfully launched TV-2 on October 23, 1957. It reached an altitude of 109 miles before coming back to Earth 335 miles downrange. As such, it was still in the category of a sounding rocket or a ballistic missile. Two weeks later, on November 3, the Soviets launched Sputnik 2, this one with a canine passenger, Laika, which became the talk of the world. Laika would not return alive from her trip into space.

The launch of the Sputniks may have raised blood pressures at NRL, but an unfortunate miscommunication following a White House briefing by Hagen and several colleagues on Project Vanguard would raise pressure to the bursting point. Hagen recalled what happened: “we briefed President Eisenhower, giving him a very factual report of our standing and telling him that we had planned in December to launch the first full-fledged test vehicle in the Vanguard program, emphasizing it was only a test vehicle which had a very remote bonus—a satellite. This was the TV-3, the first attempted launching of a complete Vanguard vehicle with all three live stages.”³⁷

Although TV-3 always had been planned as an engineering test whose outcome would help the Vanguard team build toward the real thing, perceptions that it actually was the real thing—and suddenly also the nation’s answer to Sputnik—were about to get way out of hand. On November 11, 1957, shortly after the briefing, James Hagerty, Eisenhower’s press secretary, released a White House statement saying that Project Vanguard would launch a satellite in the near future. “In other words,” Hagen said, “our first live three-stage launching was billed as a satellite launching success in advance and committed us to a public deadline with an untried vehicle.”³⁸ Once released, there was no stopping the media frenzy. No matter what the rocket scientists might have intended, the U.S. citizenry was convinced that NRL would launch the U.S. answer to Sputnik at the very next Cape Canaveral firing on December 6.

On that day, with the world watching, and after several tension-amplifying weather delays, the countdown went to zero. Friedman later recalled the moment. “When the rocket flame ignited on December 6, the vehicle rose only a little over a meter and faltered. As it fell back, the fuel tanks ruptured and the rocket rumbled to the ground enveloped in hellish flames and billowing smoke. From the top of the three-stage rocket the silvery 6-inch satellite plummeted 25 meters through the flames and bounced on the concrete deck. There our wounded bird, its antenna badly bent, radiated a futile signal at 108 megahertz.”³⁹

In an interview 52 years after the disastrous failure, Martin Votaw, who had built the transmitters inside the satellite, recalled that after crews had cleaned up the site, he actually was able to retrieve the injured, would-have-been spacecraft, place it in a cardboard box, and hand it off to Roger Easton. According to a written account by Easton’s son, Richard, and coauthor Eric Frazier, Roger Easton “nonchalantly carried the box with satellite aboard a commercial flight back to Washington, DC,” where it first sat on his kitchen table. He later brought the sorry memento of one of the worst moments in the history of American technology to the director of the Vanguard pro-



In the Hot Seat. When the Soviet Union launched Sputnik, the world's first satellite, on October 4, 1957, pressure skyrocketed on NRL's Project Vanguard to quickly match the feat by launching a Vanguard satellite as part of the International Geophysical Year. Shown here is Project Vanguard director Dr. John Hagen explaining how the launch would unfold. The first attempt, on December 6, 1957, would be a spectacular failure, but the successful launch on March 17, 1958, would ultimately vindicate NRL and Project Vanguard. (NRL photo 81968(5).tif)

gram, John Hagen, who ultimately would hand it off to curators at the Smithsonian Institution's National Air and Space Museum on the national mall in Washington, DC.⁴⁰ Today, in this museum, only steps away from the satellite is a backup Vanguard rocket that also enjoys a second life as a monument to the early Space Age.



The Almost Satellite. On December 6, 1957, in the context of NRL's Project Vanguard, the United States attempted to match the Soviets' October 4 achievement of placing a satellite into orbit. The launch failed, and the TV-3 test satellite fell out of the rocket fairing; it was subsequently retrieved, burnt and battered, at the launch site. This artifact of a historical failure now resides in the Smithsonian's National Air and Space Museum on the national mall in Washington, DC. (NRL photo 255-PV-VAN-1082 TV-3 SATELLITE 3.jpg)

Amidst all of the subsequent report-writing and public humiliation, Hagen and his team, inveterate engineers that they were, still had a test schedule to complete. The failure also stimulated, in the words of one analyst, "more careful engine system tooling and rocket construction techniques by GE and [Glenn L. Martin], respectively, in preparation for future Vanguard firings."⁴¹

But there would be no mercy. On January 22, a series of delays scrubbed the scheduled flight of America's second attempt to answer the two Sputniks. The ridicule was brutal. "The Soviet delegation to the United Nations jokingly offered to include us in the USSR program of technical assistance to developing nations," Friedman recalled.⁴² The joke at the Pentagon was a new Navy salute—a hand clasped to the forehead.⁴³ The media ran articles and commentaries that referred to the failed Vanguard as "Sputternik," "Goofnik," "Dudnik," and "Kaputnik."⁴⁴

Stuck plugs and a leaky fuel system on subsequent days prolonged the delay. That's when Wernher von Braun and his rocket crew with the Army Ballistic Missile Agency (ABMA), working with the Jet Propulsion Laboratory, received presidential



Flopnik. The failure of TV-3 elicited scathing derision, as evidenced by the headline of this front-page newspaper article. (1720067_orig.gif, <http://turningpointsthespacepace.weebly.com/the-space-race.html>)

authorization to launch a Jupiter C missile topped off with a satellite, dubbed Explorer 1, instead of its intended payload, a nuclear warhead. The ABMA-JPL team had pinned to become the Stewart Committee's original choice for the IGY satellite, but the Committee and President Eisenhower were concerned the team's primary mission—to develop intermediate-range and intercontinental ballistic missiles—was opposite to the scientific context the country wanted this satellite to reside within. The launch of the first Sputniks before any U.S. satellite made it to orbit, however, shifted the administration's priorities.⁴⁵

Providing some solace to the Vanguard team, the Army satellite was fitted with an electronics package the NRL team had built for a Vanguard satellite.⁴⁶ The "Vanguard electronic stack was adapted to a cylindrical instrumentation package that would remain attached within a fourth-stage rocket casing after burnout and orbit as a 31-pound, 80-inch long, bullet-shaped satellite," recounted a 2002 version of a classified history of early U.S. space-based reconnaissance.⁴⁷

On the night of January 31, 1958, a four-stage version of the Jupiter C rocket, dubbed Juno 1 (the name of Roman god Jupiter's wife and sister),⁴⁸ did not explode in front of the world's eyes. Instead, it carried the Explorer 1 into orbit where it began circling the Earth as the country's first satellite (and the world's third satellite), a fact all too clear to the NRL team tracking its orbit with the Minitrack system they had built specifically for tracking Vanguard satellites. In the end, it was the Army, not the Navy, which Americans would remember as first meeting the Soviets in the space race.

Hagen's ordeal was not yet complete. After several more delays in early February, another satellite-tipped Vanguard rocket, the TV-3BU (BU stands for backup), finally lifted off on February 3, 1958. But a control system malfunctioned after 57 seconds of flight, resulting in the loss of attitude control. A subsequent investigation revealed, in the words of historians Green and Lomask, "that spurious electrical signals had

created motions of the first-stage engine in the pitch plane. These in turn developed dynamic structural loads, coupled with a rapid pitch-down that superimposed air loads of about the same magnitude. As a result, the vehicle broke up at the aft end of the second stage.”⁴⁹ On March 5, the Army was hit with its own failure. The fourth stage of a Redstone rocket carrying the Explorer 2 satellite did not ignite. Rather than entering an orbital trajectory, both the rocket and satellite fell into the Atlantic Ocean.⁵⁰

During the next weeks, the next launch attempt by Project Vanguard, with TV-4, was delayed multiple times, including once when a plug involved in the fuel pressurization process failed to come free. What everyone hoped would be the final countdown began to unfold early on St. Patrick’s Day, but it wasn’t smooth. Note Green and Lomask: “At 6:50 a.m. there was a short hold: more electronic problems. At almost literally the last second, there was another and even shorter hold, or more exactly, a ‘stretch-out,’ when calculations showed that if the countdown concluded at that moment, Explorer I would be passing overhead just as TV-4 arched into the heavens. Passage of the Army satellite at that time, according to the electronics men, might interfere with the signals from the Vanguard payload.”⁵¹

The luck of the Irish finally came Hagen’s and NRL’s way at 7:15 a.m. It might have been “5 months and 13 days after the launch of Sputnik I, and about 6 weeks after the launch of Explorer,”⁵² but on this day a Vanguard rocket soared upward to deliver its satellite payload into orbit.



Final Assembly. Vanguard team member Dave Corbin assembles the Vanguard 1 satellite flight unit in preparation for the March 17, 1958, launch. (*NRL photo Votaw_1.jpg*)

The orbit of Vanguard 1, a 6-inch-diameter sphere that Soviet premier Nikita Khrushchev later would refer to as “the grapefruit satellite,”⁵³ entered an elliptical orbit with its farthest point from Earth (apogee) at 3,966 kilometers and its closest point (perigee) at 653 kilometers. Although Project Vanguard suffered adversities in the realm of public relations, and continues to be misperceived as a failure, it was an as-



Vindication Liftoff. Following the terrible failure of TV-3 in front of the world on December 6, 1957, the Vanguard team celebrated their successful launch from Cape Canaveral of the Vanguard 1 satellite on March 17, 1958. (NRL photo 78439.jpg)

tounding achievement in rocketry from an engineering point of view. In just two and a half years, a new rocket system and scientific satellite for the International Geophysical Year had gone from an all-paper design stage to a successfully launched satellite. NRL's Jay Middour, head of the Advanced Systems Technology Branch at NRL as this book was being researched and written, and Patrick Binning, an aeronautical engineer who has worked at NRL and in managerial roles at NRL partner organizations, such as the National Reconnaissance Office, summed it up this way in a paper they prepared for the American Astronomical Society:

“Vanguard met 100 percent of its scientific objectives, providing information on the size and shape of the Earth, air density, temperature ranges, [and] micrometeorite impact, and improved the accuracy of world maps. Project Vanguard established a number of scientific and engineering firsts. The rocket employed a strapped-down gyro platform, and rotatable exhaust jets on the first stage engine for roll control, and a C-band radar beacon. The Vanguard I satellite achieved the highest altitude of any man-made vehicle to that date. It was the first solar powered satellite and the first to use miniaturized circuits. Observations of its orbital motion established a very accurate value for the flattening ratio between equatorial and polar Earth radii and established beyond doubt geologists' suspicions that the Earth is pear-shaped.”⁵⁴

The satellite remains in orbit today and stands as the oldest human-made object in space.

A month after this stupendous win, the Vanguard team tallied a string of losses. The launch of Project Vanguard's final test vehicle, TV-5, on April 28, 1958, experienced problems in its second stage and failed to make orbit. And so too did the 9.8-kilogram, 50.8-centimeter spherical satellite enclosed within it, which carried

instruments for measuring aspects of the space environment, including intensity variations in X-rays arriving from the sun.⁵⁵ The next three launches of the Project Vanguard's planned SLV vehicles, the ones that were supposed to stand a better chance of making it to orbit based on lessons learned from the test vehicle (TV) series, all failed due to attitude, propulsion, and other performance problems with the second and third stages. The first stage, the one derived from the Viking programs, proved to be the most reliable overall.

NRL itself would never get to launch SLV-4, SLV-5, or SLV-6, or TV-4BU (also known as SLV-7), which was another backup (BU) vehicle still on hand. These four vehicles—two of which would fail and two of which would place Vanguard 2 and Vanguard 3 satellites into orbit—would become learning launches during the first year of a brand new civilian space agency, the National Aeronautics and Space Administration, which quickly would become a household name. NASA was established by an act of Congress on July 29, 1958, and began operating just over two months later.

Although NRL did not launch the last of the Vanguard rockets, it was essentially the NRL team that did: by law, the entire Project Vanguard team, about 160 people, had been transferred to NASA where it “became the human core of the Goddard Space Flight Center at Greenbelt, MD,” according to project director Hagen, who was among the transferees.⁵⁶ About 40 NRL staff from other divisions also transferred. Instruments on the 71.5-pound Vanguard 2 carried into orbit aboard SLV-4 on February 17, 1959, measured reflectivity characteristics from the topsides of clouds. The satellite remains in orbit and will be there for many years to come. Seven months later, on September 18, 1959, the final satellite of the series, Vanguard 3, was launched into orbit with the backup test vehicle, TV-4BU (SLV-7). The 52-pound spacecraft carried sensors that measured X-rays, Lyman-alpha radiation (certain ultraviolet wavelengths), and space environment conditions, including temperature and magnetic field strength.⁵⁷ The Van Allen radiation belts ended up swamping the radiation detectors, but the satellite provided temperature measurements over a stretch of 77 days. Data about Earth's magnetic field, magnetic disturbances, lightning-induced ionization in the upper atmosphere, and interplanetary cosmic dust particles poured in from the satellite. The dust measurements, for one, indicated that some 9 billion kilograms of extraterrestrial matter was raining down on the planet every day.⁵⁸

In addition to Project Vanguard space science successes, the engineering legacy of the Vanguard rocket designs would trace forward through future NASA and Air Force vehicles. Meanwhile, the Minitrack system would feed into the evolution of much of the nation's radio-based satellite tracking, including the advanced and comprehensive naval space surveillance system known for short as NAVSPASUR, or sometimes simply SPASUR. With NAVSPASUR, the U.S. could detect unannounced launchings of satellites by foreign nations even if those satellites were silent and not broadcasting signals of their own as Sputnik had done.⁵⁹

To Hagen, none of these technical achievements were the most important outcomes of NRL's pioneering thrust into orbit. "The greatest achievement of Project Vanguard," he opined, ". . . was the development of a group of dedicated and talented scientists and engineers who came to understand thoroughly, perhaps the hard way, the overall complexities of the space programs."⁶⁰

For NRL, though, the transfer of Project Vanguard's personnel and hardware to NASA in 1958 could have ended the lab's status as a player in the still young arena of space technology. But a small contingent of visionaries would set NRL off into yet another pioneering Space Age venture, one they would have to keep deeply secret for 40 years.

¹ Homer E. Newell, *Beyond the Atmosphere: Early Years of Space Science* (NASA SP-4211), (Washington, DC: National Aeronautics and Space Administration, 1980), Chapter 5.

² Constance Green and Milton Lomask, *Vanguard: A History* (Washington, DC: NASA, 1970), available online at <http://history.nasa.gov/SP-4202/toc2.html>; Homer Newell, "Artificial Earth Satellite Program for the IGY," April 15, 1956; John Hagen, "The Viking and the Vanguard," *Technology and Culture* 4, no. 4 (1963): 435–451.

³ Newell, "Artificial Earth Satellite Program"; Hagen, "The Viking and the Vanguard."

⁴ See, for example, Paul Dickson, *Sputnik: The Shock of the Century* (New York: Walker & Company, 2001).

⁵ Green and Lomask, *Vanguard*.

⁶ Green and Lomask, p. 18.

⁷ Green and Lomask, *Vanguard*.

⁸ P.W. Binning and J.W. Middour, "A Brief History of NRL's Early Firsts in Spaceflight," *Advances in Astronautical Sciences*; 129 (2008): 1233–1250.

⁹ David Portree, *NASA's Origins and the Dawn of the Space Age* (Monograph in Aerospace History, No.10), July 1998; available online, <http://www.hq.nasa.gov/office/pao/History/monograph10/>.

¹⁰ Binning and Middour, "A Brief History."

¹¹ Hagen, "The Viking and the Vanguard," p. 439.

¹² Ivan Amato, *Pushing the Horizon: Seventy-Five Years of High Stakes Research and Technology at the Naval Research Laboratory* (Washington, DC: Naval Research Laboratory, 1998), see Chapter 8; Hagen, "The Viking and the Vanguard," p. 438.

¹³ See, for example, papers associated with the conference "Reconsidering Sputnik: Forty Years Since the Soviet Satellite," which was held at the Smithsonian Institution from September 30 to October 1, 1997. In particular, see Dwayne A. Day's "Cover Stories and Hidden Agendas: Early American Space and National Security Policy" and Kenneth A. Osgood's "Before Sputnik: National Security and the Formation of U.S. Outer Space Policy, 1953–1957." The conference proceedings were later published as a book: *Reconsidering Sputnik: Forty Years since the Soviet Satellite*, edited by Roger D. Launius, John M. Logsdon, and Robert W. Smith (Amsterdam: Harwood, 2000).

¹⁴ Hagen, "The Viking and the Vanguard," p. 439.

¹⁵ Hugh Sidey, "The Man Who Took the Beating for Vanguard," *Life Magazine*, March 31, 1958, p. 35.

¹⁶ Hagen, "The Viking and the Vanguard," pp. 441–442.

¹⁷ The fuel featured fuming nitric acid and a highly explosive form of dimethylhydrazine.

¹⁸ Hagen, "The Viking and the Vanguard," p. 441.

- ¹⁹ Hagen, "The Viking and the Vanguard," p. 442; Charles Merguerian, "The Vanguard Program," in F. N. Magill, editor, *Magill's Survey of Science, Space Exploration Series* (Pasadena, California: Salem Press, Inc., 1989).
- ²⁰ Hagen, "The Viking and the Vanguard," p. 443.
- ²¹ John Hagen, "Vanguard—The Laboratory Ventures Into Space," in *NRL Progress* (Washington, DC: Naval Research Laboratory, 1973), p. 31.
- ²² Hagen, "The Viking and the Vanguard," p. 446.
- ²³ Hagen, "The Viking and the Vanguard," p. 442.
- ²⁴ Sunny Tsiao, "*Read You Loud and Clear!*": *The Story of NASA's Spaceflight Tracking and Data Network*, NASA SP-2007-4233 (Washington, DC: National Aeronautics and Space Administration, 2008).
- ²⁵ Tsiao, "*Read You Loud and Clear!*," p. 10.
- ²⁶ Tsiao, p. 8.
- ²⁷ Tsiao, p. 9.
- ²⁸ Tsiao, p. 11.
- ²⁹ Tsiao, p. 9.
- ³⁰ Tsiao, p. 12.
- ³¹ Tsiao, p. 12.
- ³² Tsiao, p. 13.
- ³³ <http://history.nasa.gov/computers/Part3.html>; <http://history.nasa.gov/SP-4202/chapter9.html>.
- ³⁴ Hagen, "The Viking and the Vanguard," p. 447.
- ³⁵ Sidey, "The Man Who Took the Beating for Vanguard," p. 35.
- ³⁶ Herbert Friedman, "Reminiscences of 30 Years of Space Research" (Washington, DC: Naval Research Laboratory, August 1977), p. 16.
- ³⁷ Hagen, "The Viking and the Vanguard," p. 438.
- ³⁸ Hagen, "The Viking and the Vanguard," p. 448.
- ³⁹ Friedman, "Reminiscences," p. 16.
- ⁴⁰ Richard D. Easton and Eric. F. Frazier, *GPS Declassified: From Smart Bombs to Smartphones* (Potomac Books: A University of Nebraska imprint, 2013).
- ⁴¹ Merguerian, "The Vanguard Program," pp. 2077–2082.
- ⁴² Friedman, "Reminiscences," p. 16.
- ⁴³ Sidey, "The Man Who Took the Beating for Vanguard," p. 36.
- ⁴⁴ Dickson, *Sputnik*, pp. 158–159.
- ⁴⁵ Dickson, *Sputnik*, pp. 84, 87, 147–149.
- ⁴⁶ Binning and Middour, "A Brief History."
- ⁴⁷ Binning and Middour, "A Brief History," p. 5. Binning and Middour cite a document by Ronald L. Potts, an insider-chronicler of National Reconnaissance Office history. The reference reads as follows: "R.L. Potts, unpublished, classified work in progress on America's early ELINT satellites, June 3, 2002 version."
- ⁴⁸ Dickson, *Sputnik*, p. 170.
- ⁴⁹ Green and Lomask, *Vanguard*.
- ⁵⁰ Green and Lomask, *Vanguard*.
- ⁵¹ Green and Lomask, *Vanguard*.
- ⁵² Binning and Middour, "A Brief History."
- ⁵³ <http://www.nrl.navy.mil/vanguard50/legacy.php>.
- ⁵⁴ <http://www.nrl.navy.mil/vanguard50/legacy.php>; R. Jastrow, "Results of the Space Science Program," *Proceedings of the American Philosophical Society*, 106, no. 1 (Feb. 15, 1962): 82–87.
- ⁵⁵ Green and Lomask, *Vanguard*.
- ⁵⁶ Hagen, "The Viking and the Vanguard," p. 451; Lane E. Wallace, *Dreams, Hopes, Realities: NASA's Goddard Space Flight Center, The First Forty Years* (Washington, DC: National Aeronautics and Space Administration, 1999), pp. 18–19.
- ⁵⁷ Green and Lomask, *Vanguard*.

⁵⁸ Merguerian, "The Vanguard Program," p. 2081.

⁵⁹ Tsiao, "*Read You Loud and Clear!*".

⁶⁰ Hagen, "The Viking and the Vanguard," p. 451.

6

THE LORENZEN FACTOR

The Naval Research Laboratory became a bastion of world-class rocket engineering in the 1940s and 1950s. Even Project Vanguard, which the world remembers mostly for the spectacular launchpad failure of December 6, 1957, ended up successfully fulfilling its technological and scientific goals, so much so that its hardware (as in the Vanguard rocket and orbital tracking technology) and its brainware (the project's engineering personnel and some of its upper atmosphere science researchers) became a prominent part of the nation's civilian space program with the establishment of NASA in 1958.

All the while, another essential thread stemming from NRL's work to counter World War II with innovative electronic countermeasures, such as radar jammers, was developing in a lower-profile, more secret way. It was a thread that would combine with the lab's growing rocket-mindedness. In time, these institutional traits would usher NRL into becoming one of the nation's most innovative and consequential centers of space technology for military and security purposes.

The 1950s was a decade of grinding Cold War fear and peril. It was a time when the dearth of information about the Soviet Union was so deep that national leadership was determined to push intelligence, surveillance, and reconnaissance (ISR) technology at an unprecedented pace. No one at NRL leveraged this context more effectively than Howard Otto Lorenzen—"Harv" to his friends.¹

He became known as the father of electronic warfare because of his innovations and leadership during World War II. After the war, he got the lab used to thinking big. His focus had been on developing radio- and electronics-based means of protecting floating and airborne military assets from enemy radar tracking, guided missiles, and other threats that depended on reception or emission of radio, microwave, and other electromagnetic wavelengths. Beginning in the late 1950s, Lorenzen would be one of the lab's driving forces for steering the in-house talent in the direction of intelligence, reconnaissance, and surveillance from space.

Lorenzen had been working at Zenith Radio in Chicago, Illinois, designing commercial radios and components, when he got a job offer from NRL in 1940.² This was a time when the lab's radar pioneers, among them Dr. A. Hoyt Taylor, Dr. Robert Page, Dr. Louis Gebhard, and Dr. John Hagen, had convinced Congress that it needed to support the development of radar technology for the war effort. When the lab offered a renewable, annual contract with a starting salary that was more than he was making at Zenith, the 28-year-old Lorenzen accepted the position.



Father of Electronic Warfare. Howard Otto Lorenzen, shown here in a 1958 photograph, became known as the father of electronic warfare for his work during World War II, which he followed in the Cold War with work on, among other projects, electronic intelligence (ELINT) satellites. (*NRL photo Lorenzen(2).jpg*)

The primary radar mission at the time was to protect battleships, aircraft carriers, cruisers, and other ships in the Navy's fleet from air attack by providing them with the means for spotting hostile aircraft or guided missiles from far enough away and with enough time to do something about them. The workhorse technology was in the form of a 200-megahertz, 15-kilowatt search radar. Lorenzen demonstrated his aptitude and originality in the electronics arena by building a lightweight version of the system that operated at twice the frequency, 400 megahertz. It was one of his first assignments in the Special Projects Section of the Radio Division.³

A search radar working at the shorter wavelength would reveal more precise locations and trajectories of aircraft, missiles, and other objects, but the system required new designs for just about every part of its anatomy. The task required new sensitive, high-gain antennas, for example, and Lorenzen knew he needed to build anti-jamming features into the system. "We started from scratch," Lorenzen said. "We developed everything that was in the receivers, the indicators, and transmitters."⁴ Once Page, Lorenzen, and their colleagues made modifications, the new NRL-designed-and-built 400-megahertz unit became a prototype for production.⁵ In July 1941, five months before the U.S. entered World War II by way of the surprise attack by Japan on the country's Navy base in Pearl Harbor, Hawaii, this unit was successfully proven on the destroyer USS *Semmes*. RCA and General Electric then got busy manufacturing production units for installation on the fleet's destroyers and smaller vessels.⁶

Early in his NRL career, Lorenzen developed a deep appreciation for the military opportunities and pitfalls inherent in the exploitation of, and reliance upon, electromagnetism, including the radio frequency (RF) and microwave portions of the electromagnetic spectrum. The learning curve was steep in the radar business and Lorenzen quickly got a feel for how vulnerable radar receivers were to jamming. A radar engineer working a few stories above where Lorenzen and some colleagues were working came over to him with a question: "You guys got anything operating around 200 megahertz?" Lorenzen answered that they did. "Leave that darned thing off," the radar engineer said. "You are jamming our radar in the penthouse and we can't see anything on the scope." It was Lorenzen's first encounter with radar jamming.⁷

“This made quite an impression on me,” Lorenzen recalled, indicating how impressed he was at how easy it was to jam radar equipment at the lab, which means jamming surely would be a major vulnerability for ships at sea.⁸ A short time after that, British RF scientists gave Lorenzen and his radar-engineering colleagues at NRL a classified briefing about their work. They told us, Lorenzen recalled, “how they were jamming German radars and how they were doing deception . . . We weren’t authorized to discuss anything, but they were trying to get us interested.”⁹

Lorenzen was so precocious in his first year at NRL that the Radio Division’s superintendent, A. Hoyt (“Doc”) Taylor, and Assistant Director Louis Gebhard rewarded him in several ways. They turned a blind eye to the machine shop Lorenzen had set up to fabricate engineering models. This move by Lorenzen was a deliberate end run around lab policy and practice, which would have had him relying on a centralized machine shop. Taylor and Gebhard also kept adding more jobs and responsibility onto Lorenzen’s shoulders. They assigned to him more and more engineers and technicians to supervise. He was an obvious talent and the division leadership wanted to let him fly at a time when the war in Europe was taking ominous turns. In December, when the U.S. was drawn into the war by the Pearl Harbor attack, Lorenzen supervised an ever-accelerating pace of innovation and production of radar systems—including transmitters, receivers, cathode ray tube displays, and motors for sweeping the antennas across the sky—for ships, aircraft, and onshore installations.¹⁰

Upon installation in the fleet, the value of the technology for carrying out military operations, defending against enemy actions, and saving the lives of U.S. and Allied servicemen became evident. With a constant drive to improve the technology and develop more capable and more compact versions and variations that could find uses in more venues and tactical situations, Lorenzen sought out and interacted with radar scientists elsewhere. He established contacts with his cohorts in Britain and at MIT’s Radiation Laboratory, for example, and with the National Defense Research Committee, which was coordinating wartime R&D in multiple categories in the United States. He could not have known then how his networking would open doors later that would change the laboratory and the character of national security and defense.

As Lorenzen remembered it during a discussion with a historian,¹¹ he and the lab first got into countermeasures and electronic warfare as a result of German innovations in air-launched guided bombs. During the invasion of Solarino, on Sicily’s east coast, he noted, the Navy retrieved an errant radio-guided bomb that had gone down in shallow waters without exploding. “It was immediately rushed here to NRL,” Lorenzen said. The lab’s chief radio scientist, Doc Taylor, assigned Dr. Ernst Krause to lead a team, including Lorenzen, “to analyze this thing and get some equipment out that would counter it.” It was a high-priority effort at NRL and included the Special Projects Section, which included Lorenzen’s machinists and others who had a reputation, Lorenzen noted, “for turning stuff out, and in good shape, and in rapid time.”¹²

Ronald L. Potts, a participant in NRL's and the nation's emerging intelligence-gathering technologies in the 1960s and who later became a historian of the same, recounted how Lorenzen took on this project: "He developed a system installed on two destroyer escorts to intercept, record magnetically on steel wire, and analyze German aircraft radio signals that controlled the glide bombs built to sink allied warships in the Mediterranean Sea. The knowledge helped NRL's Special Projects Section develop intercept-jammers that defeated the Henschel-293 [glide bomb] system, and the unwitting Luftwaffe engineers concluded that the RF energy was too fickle or pilots too inept to make the intricate control system work as designed."¹³

Thwarting enemy jamming and eavesdropping on enemy radio frequency emissions and signals became the deadly serious sport of Lorenzen and his fellow RF wizards. Their approach to the challenge and their successes earned NRL a superlative reputation in the arena of electronic intelligence, or ELINT. This is a category of intelligence that listens in on electromagnetic signals, such as those used by radar systems, whether for search and tracking purposes or for targeting and controlling munitions.¹⁴ The same principles and technologies soon would apply in another emerging venue for warfare and national security: space.

Even as he was pushing technology development at NRL, Lorenzen also was ensconcing himself intricately with decision makers, policy bodies, and other components of what would become a complex infrastructure overseeing electronic warfare, countermeasures, and the nation's overall signals intelligence (SIGINT) program, which included ELINT. During World War II, teams of NRL personnel frequently traveled to war zones to install countermeasures equipment and train servicemen how to use it. On those forays, the NRL staff wore special military-like uniforms, labeled "U.S. Technician," to reduce the likelihood they would be accused of spying in the event they were captured by the enemy.¹⁵

Among those NRL engineers and technicians was a young and stout Reid Mayo, who arrived at the lab for the first time at the very end of 1943, after a stint at the Navy's Radio Material School in Illinois where he learned to maintain and repair radio equipment.¹⁶ At NRL he trained as a technician in radio countermeasures with the Special Projects Section and spent most of the war in the Northern Pacific installing countermeasures equipment on ships and training crew members in its use. Just before Mayo was deployed, he became the first NRL employee to get married in what was then a brand new chapel on the NRL campus, commissioned earlier on the wedding day!¹⁷ Mayo also saw combat in 1945 in the Okinawa campaign and was on a ship near Japan when the U.S. dropped the atomic bomb on Hiroshima.¹⁸

After the war, Mayo returned to Washington, DC, earned a degree in electrical engineering from George Washington University, and then returned to NRL as a new hire in 1949 in Lorenzen's recently established Countermeasures Branch in the Radio Division.¹⁹ Nine years later, Mayo would have an aha! moment, an insight as simple as it was ingenious, while holed up at a Pennsylvania restaurant with his family during



Countermeasures Man. Shown here on the day of his marriage to Margaret Block, Reid Mayo had installed countermeasures equipment on ships during World War II and a decade later helped to bring some of the lessons learned into space. (*NRL photo Mayo(1).jpg*)

a late spring snowstorm. That moment would help determine and differentiate NRL's role in the U.S. space program throughout the Cold War.

While Mayo was still in the Pacific installing countermeasures devices on ships, the country began mobilizing all the scientific and engineering talent and know-how it could muster in a goal to defeat Germany and its allies. Among the lasting organizational innovations that emerged at this time were national-level oversight and planning bodies, including the National Defense Research Committee (NDRC), which later became the Office of Scientific Research and Development (OSRD). These organizations became models for the establishment of the Office of Naval Research (ONR) in 1946 and the civilian version, the National Science Foundation (NSF), in 1950.

The call for accelerating technological developments could not have come from higher places. Just before the U.S. entered World War II, President Franklin D. Roosevelt called on NRL to conduct frank and open exchanges with British radar experts. Lorenzen was the lab's point man for this mandate. And those new liaisons would evolve into an intense collective effort by the Allies' engineers to predominate in the electromagnetic spectrum.²⁰ In a key acquisition that would feed into some of the most important countermeasures work the lab would do in the 1940s and 1950s, Lorenzen and several like-minded coworkers from the nearly dozen small groups he supervised during the war procured a cache of electronic equipment from Germany and Japan that Allied forces had captured in Europe and Asia.

By the end of the war, Lorenzen had earned himself a status as the nation's human hub for just about all things regarding what he and then others came to think of as ECM, or electronic countermeasures, as a way to generalize the field beyond merely radio countermeasures. If the Pentagon had a question about, for example, whether the enemy could use some kind of electromagnetic signal to cause one of the country's nuclear bombs to detonate prematurely, Lorenzen would be a go-to guy to get an answer.²¹

His managerial and leadership skills also brought tremendous credibility and support to the lab. "Sponsorship for NRL's intercept, direction finding, jamming, and

decoy systems came from the Navy Bureaus of Ships and of Yards and Docks, which also shepherded transitions to industry for systems produced in quantity,” Potts wrote in a profile of Lorenzen.²² He was becoming an ever more influential force in the policy-making and leadership side. For example, during the war, Potts noted, Lorenzen “was a key member of a countermeasures partnership between NRL and the Office of Naval Intelligence in the Pentagon, which interfaced with the NDRC Division 14 (countermeasures) and industry.”²³

After the war, Lorenzen maintained and nurtured the military and civilian contacts he had made and continued to expand upon these. His role on committees and working groups associated with present and future countermeasures needs continually increased in the post-war years. In time, Lorenzen’s employment status took a great leap upward when he was designated as a presidential appointee (under the World War II-era Public Law 313, which gave the President a portfolio of powers in the interest of national security). This status change gave Lorenzen an enormous amount of power, access to decision makers at the highest government levels, and options for circumventing bureaucratic choke points. “When need be, he explained his projects on Capitol Hill, the Pentagon, the United States Intelligence Board, the President’s Scientific Advisory Committee, the Bureau of the Budget, the General Services Administration, and the intelligence agencies (CIA, DIA, NSA, and NRO),” Potts explained.²⁴ His exceptional stature put him in a position to have, in some respects, more power and access to classified information at NRL than did even the lab’s director of research.

“I don’t think there is anybody like Howard Lorenzen at the lab today, not at a level where they are capable of effecting change personally,” observed Dr. John Montgomery, who joined NRL in 1968 where he began a long career in electronic warfare research and, in 2002, became the lab’s Director of Research until his retirement in 2016.²⁵ Consistent with Montgomery’s appraisal of Lorenzen was the singular post-mortem honor that the Department of the Navy bestowed in 2010 upon this father of electronic warfare: the christening of USNS *Howard O. Lorenzen*, a 534-foot Missile Range Instrumentation Ship brimming with advanced radar and other technologies for collecting performance and engineering data during missile launches. Only one other NRL scientist had ever been so honored and that was ocean acoustics expert Dr. Harvey C. Hayes when USNS *Hayes* launched in 1970.²⁶

But back in the late 1940s, as the Iron Curtain—a phrase famously coined by Winston Churchill—descended around the east European satellite nations of the Soviet Union and the Cold War began heating up, Lorenzen and Edwin Speakman, another of the lab’s radar and electronic countermeasures pioneers, were able to convince laboratory leadership to put more emphasis on their area of research by establishing what became known as the Countermeasures Branch.

“Lorenzen’s prior investigations of German equipment and documents soon paid off, for Soviet adaptations of German technology and techniques began to appear,”



USS *Lorenzen*. Howard Lorenzen, often referred to as the father of electronic warfare, was honored by the Navy for his pioneering contributions in electronic countermeasures by having a Missile Range Instrumentation Ship named after him. USNS *Howard O. Lorenzen* (T-AGM 25) was commissioned in 2012. Also shown here is the ship's coat of arms. (NRL photos *Lorenzen.jpg* and *Lorenzen_coat_of_arms.tif*)

noted Potts. “The Branch developed intercept and DF [direction finding] systems for deployment to Navy ships, shore stations, and aircraft.”²⁷ In the context of electromagnetic signals, the term “direction finding” refers to locating the emission sources of electromagnetic signals, whether they are from, say, a search radar on the eastern coast of Russia, a targeting radar system on a naval vessel at sea, or a command and control transmitter for a guided missile. Lorenzen, Speakman, Mayo, and those working with them at NRL were major innovators in this area, including the development of high frequency direction finding (HF/DF) technology, often known as “huff-duff.” Among other consequential payoffs, huff-duff influenced the outcome of the Cuban Missile Crisis in 1962 by enabling the U.S. to detect and track Soviet submarines making their way to Cuban waters.²⁸

Lorenzen’s success came in part from his penchant for viewing “people in the field as his clients,” noted Dr. Bruce Wald, one of the most colorful and mathematically gifted scientists in NRL’s history and who retired after serving many roles at NRL.²⁹ Wald was a central contributor in some of the lab’s then most classified initiatives such as the Huff-Duff projects known as Bullseye and Boresight. Lorenzen, who supervised these projects, “traveled extensively, largely to the Naval Security Group [for which signals intelligence was a major concern], and intelligence organizations. He traveled all over the world,” Wald said.³⁰ It is safe to say that Lorenzen had earned himself a position to think big and an expectation that at least some of his visions, including space-based ones, would be realized.

Before ELINT devices could go into orbit, they would go onto aircraft. NRL’s ELINT developments in the decade before satellites were launched included, according to Potts, the “first tunable airborne microwave intercept receiver,” installed at the end of the 1940s on P4M-1Q Mercators, PB4Y-2 Privateers, and P2V Neptunes.³¹ Similar technology became the heart also of land-based “ferret” probes distributed in

undisclosed locations along the periphery of the Sino-Soviet bloc. Still other versions of this ELINT theme were fitted on ships and submarines.³²

As the flow of ELINT intensified from an ever-increasing number of listening posts, Lorenzen and his NRL colleague Robert D. Misner, an expert in signals processing, wanted to get a feel for how the systems were working in the field and to identify shortcomings. To increase the amount of intercept data they could examine, they worked in collaboration with the Stromberg-Carlson Company, which was a major player in telecommunications and electronics technologies, to produce in 1949 the IC/VRT-7, or the Radio-Countermeasures Sound Recorder-Reproducer. They designed the unit specifically to record intercepted signals on magnetic tape for later retrieval and analysis. Noted Potts, this was the country's "first magnetic tape recorder for intercept work."³³

Lorenzen's reach into the nation's electronic countermeasures programs just kept expanding and in so doing he was helping establish an infrastructure that would underlie what would become one of the most extensive and audacious intelligence-gathering efforts in history. He helped organize a Countermeasures Intercept Analysis Group (under the auspices of an office in the Department of Defense's Joint Chiefs of Staff)³⁴ with participation and sponsorship by the highest levels of the military's technology-based commands, boards, committees, and councils. The Analysis Group would further evolve in 1955 into a national-level electronic intelligence program and the previously established Army-Navy Electronic Evaluation Group also would take a more inclusive nationalized flavor in the form of the vaguely named National Technical Processing Center (NTPC).³⁵

On the hardware side, Potts reported, "Lorenzen's countermeasures team provided equipment (antennas, receivers, recorders, analysis devices), technical support and technology transfer for various surveillance platforms—via the Navy Bureaus of Ships and Aeronautics, the Army Signal Corps (ELINT vans), the CIA Office of ELINT (U-2 aircraft, crash boats, and agent devices), and ONI [Office of Naval Intelligence] (covert installations and equipment on loan to friendly foreign navies)."³⁶

This was all happening in parallel, throughout the post-World War II years and on into the period of the Korean War, when the likes of Ernst Krause, Milton Rosen, Homer Newell, Herbert Friedman, and Richard Tousey were building up the laboratory's familiarity and expertise in rocketry, rocket-based upper atmosphere research, and ancillary technologies such as telemetry for command, control, and data management. It was all happening too when mere talk and musings about satellites was progressing in the mid-1950s toward the Space Age itself as the United States and Soviet Union pushed forward in their Vanguard, Sputnik, and Explorer programs toward the world's first orbiting satellites. For their parts, Lorenzen, Mayo, and a cadre of NRL colleagues were embarking on a startling technological adventure that stood a chance of steering the Space Age into one of its most exciting trajectories. Their ambitions and what became of them would have to remain secret for 40 years.

¹ Howard Lorenzen, oral history, conducted by NRL Historian John A. S. Pitts at NRL on October 18, 1983.

² Lorenzen, oral history; also see Ronald L. Potts, “A Tribute to the Father of Electronic Warfare,” a profile of Howard Lorenzen in *Labstracts*, November 24, 2008 (original version written in 2000 as a long obituary and printed by NRL as a press release); online version, <http://www.nrl.navy.mil/media/news-releases/2000/a-tribute-to-the-father-of-electronic-warfare>.

³ Ivan Amato, *Pushing the Horizon: Seventy-Five Years of High Stakes Research and Technology at the Naval Research Laboratory* (Washington, DC: Naval Research Laboratory, 1998), p. 119–123; Howard Lorenzen, “Short History of Countermeasures at the Naval Research Laboratory.”

⁴ Lorenzen, oral history.

⁵ Lorenzen, oral history.

⁶ Potts, “A Tribute.”

⁷ Amato, *Pushing the Horizon*, p. 120.

⁸ Lorenzen, oral history.

⁹ Lorenzen, oral history.

¹⁰ Potts, “A Tribute.”

¹¹ Lorenzen, oral history.

¹² Lorenzen, oral history.

¹³ Potts, “A Tribute.”

¹⁴ There are many categories of intelligence and at least as many acronyms associated with them. Electronic intelligence (ELINT) and signals intelligence (SIGINT) are sometimes used interchangeably. Sometimes SIGINT refers to a combination of ELINT and voice-based communications intelligence (COMINT).

¹⁵ Lorenzen, oral history.

¹⁶ Robert A. McDonald (ed.), *Beyond Expectations—Building an American National Reconnaissance Capability: Recollections of the Pioneers and Founders of National Reconnaissance* (Bethesda, MD: National Reconnaissance Office and the American Society for Photogrammetry and Remote Sensing, 2002), pp. 129–138.

¹⁷ McDonald, *Beyond Expectations*, p. 130.

¹⁸ McDonald, *Beyond Expectations*, p. 131.

¹⁹ McDonald, *Beyond Expectations*, pp. 131–132.

²⁰ Lorenzen, oral history. In the oral history with John A. S. Pitts, Lorenzen indicates he was convinced that the British use of a device, called a duplexer (which enabled the same antenna to both emit search signals and detect the echoes), emerged from its dealings with NRL. With it, he says, the British “could see clear back to the air fields in France” and so could know when the German planes had stopped taking off from airfields there. “In the Battle of Britain they committed every damn fighter that they had and the reason they could do this is because they knew there were no more [German fighters] taking off from France.” Said Lorenzen, “it was the thing that turned the tide in the Battle of Britain.”

²¹ *Labstracts*, Naval Research Laboratory, March 27, 2000.

²² Potts, “A Tribute.”

²³ Potts, “A Tribute.”

²⁴ Potts, “A Tribute.” The acronyms stand for the Central Intelligence Agency (CIA), Defense Intelligence Agency (DIA), National Security Agency (NSA), and National Reconnaissance Office (NRO).

²⁵ John Montgomery, interview with author, May 30, 2012.

²⁶ *Labstracts*, Naval Research Laboratory, July 26, 2010, pp. 1 and 6.

²⁷ *Labstracts*, Naval Research Laboratory, July 26, 2010, p. 7.

²⁸ W. Craig Reed, *Red November* (New York: Harper Collins, 2010).

²⁹ Bruce Wald, interview with author at Wald’s home on May 23, 2012.

³⁰ Wald interview.

³¹ Potts, "A Tribute."

³² Potts, "A Tribute."

³³ Potts, "A Tribute"; Reed, *Red November*, pp. 40–44.

³⁴ The group was organized in association with the Joint Communication and Electronics Committee, JCEC, of the Joint Research and Development Board, JDRB.

³⁵ Potts, "A Tribute."

³⁶ Potts, "A Tribute"; Lorenzen, oral history.

7

REPORT 5097: BEYOND VANGUARD

The greatest early threat to NRL's longevity as a player in the evolving U.S. space program derived, ironically enough, from the ultimate success in 1958 of Project Vanguard, which culminated for the lab in the St. Patrick's Day launch of Vanguard 1. The grapefruit-sized satellite placed in orbit that day stands as the oldest human-made object still circling the planet.

President Dwight Eisenhower had new plans for NRL's Vanguard team. When he signed Public Law 85-568, the National Aeronautics and Space Act, on July 29, 1958, the National Aeronautics and Space Administration (NASA) was created as an act of public policy. By then, there were pockets of rocket expertise around the country—at NRL, the Army Ballistic Missile Agency that had put Explorer 1 in orbit earlier in the year, the Air Force Cambridge Research Laboratories, the Jet Propulsion Laboratory (JPL), the Applied Physics Laboratory (APL), and several other places. The new law bestowed the President with the authority to transfer to NASA “any functions ... of any other department or agency of the United States, or of any officer or organizational entity thereof, which relate primarily to the functions, powers, and duties of [NASA].”¹

“It was a foregone conclusion that NRL's Vanguard group—150 strong—were to become part of NASA, as they did on November 16, 1958,” according to one of NASA's own accounts of its early history.² Although different accounts of the NRL-to-NASA transfer cite different specific numbers in this transfer, most indicate that approximately 200 NRLers became part of NASA's initial staff. The NASA account of the early days of the Beltsville Space Center (as the Goddard Space Flight Center was known originally)³ breaks down the transfer in more detail. The account specifies that 157 NRL staff from Project Vanguard transferred in the first and largest wave just after the official opening of NASA, followed by another 47 scientists from the Rocket Sonde Research Section in December, and then finally another 15 NRL scientists, who joined NASA's new Theoretical Division.^{4,5} Even some of the original hardware that enabled the Beltsville Space Center to get its operations going transferred over from NRL. Of the seven rockets that NASA inherited from previous rocket programs, one was a Vanguard rocket that NRL never got to use. And to complete the package, NRL transferred to NASA the nine-station Minitrack system that John Mengel and Roger Easton had devised as part of the IGY-inspired Vanguard program. The tracking system went over to NASA control in 1959, after which it was upgraded with two more stations and served as the primary satellite-tracking system for the fledgling

civilian space program until 1962 after which it evolved into the Space Tracking and Data Network (STADAN).⁶

The leaders of Project Vanguard when they were at NRL—including Dr. Homer Newell, Milton Rosen, and Dr. John Hagen—took over high-level positions at NASA's headquarters in downtown Washington, DC. These men and their many NRL colleagues who worked on the rockets from the V-2 days onward through the Viking and Vanguard programs were among that group of people responsible for the ascent of NASA and its subsequent public identification as the focal point for the advent of the Space Age in the United States. From the NASA that these NRL pioneers helped to create—in their case, by comprising part of the original technical expertise at the Goddard Space Flight Center—would come planetary orbiting and robotic landing missions, flyby and landing missions, and orbiting astronomy and astrophysics laboratories including the Hubble Space Telescope and the Chandra X-ray observatory.

Once at NASA, the transferred Vanguard team orchestrated three more Vanguard launches and then closed out the program at a total cost of \$110 million. But the Vanguard science and technology teams, and lessons learned in the management of large and complex systems such as rockets and spacecraft, left a legacy. Many NASA and Department of Defense space systems would build upon advances made within the auspices of the Vanguard program in areas ranging from rocketry, lightweight materials, miniaturized electronics, solar power, rechargeable batteries, thermal control, payload command, telemetry, and tracking.⁷

The creation of NASA and the wholesale transfer of NRL's Project Vanguard to Greenbelt where the group became known as NASA-Vanguard Division could have been a deathblow to NRL's dozen-year advance into the emerging Space Age. But even before the actual transfer had taken place, NRL leadership anticipated that space technology and science would have to become a permanent part of the lab's fabric. In February 1958, five months before the legislative act that would create NASA, NRL's Director of Research, Robert Morris Page, appointed an "Ad Hoc Committee on Rocket, Satellite, and Space Research" to assess NRL's program in space research and to recommend a long-range research program. Not surprisingly, the committee concluded "the Navy must have a research program in space and will look to the Laboratory for a part of this effort. To provide proper response to the Navy needs in this regard, the only logical conclusion is that the Laboratory must strongly support a program in space research."⁸

One catalytic consequence of this soul-search was the establishment of the Satellite Techniques Branch (Code 5170) to, in the words of one laboratory summary of this action, "provide a technical core around which a Navy competency in satellite research and development could be maintained and developed."⁹ Some 200 NRL space technology and science pioneers might have moved their offices and labs 18 miles north to NASA's new Goddard campus, but a few deliberately transferred back to NRL to restock NRL with the initial skill sets it would need for the Satellite Techniques Branch.

Some of these post-NASA roots, the ones that stem back to Ernst Krause's countermeasures program from World War II and to Howard Lorenzen's comprehensive vision of the versatility and military significance of electromagnetic signals, would grow into an invisible yet enormously consequential component of the country's space program. By necessity, this extension of NRL's space mission would submerge into deep secrecy. It would have everything to do with the Cold War imperative to prevent another Pearl Harbor, one in a new era in which nuclear weapons rather than conventional munitions could be what would fall on Americans.

One of these space-minded Cold Warriors was Martin (Marty) Votaw, who had originally transferred by law to NASA with the rest of Project Vanguard's personnel, but then jumped on the earliest opportunity to reapply to work at NRL. Votaw originally had joined the lab in 1947 when he began work on radar antennas and later focused on radio frequency (RF) systems for missile tracking on the Viking and Vanguard programs.¹⁰



Satellite Maverick. Martin Votaw advocated that NRL maintain a strong capability in the satellite engineering business even as the entire Project Vanguard, and thereby most of NRL's rocket and satellite expertise, transferred in 1958 to the newly formed NASA. Votaw is shown here in 1961, soon before he left NRL to become part of the fledgling satellite-based telecommunications industry. (NRL photo VotawM(1).tif)

“Votaw convinced people that staying in space was important and that the Navy shouldn't get out of the business,” recounted Peter Wilhelm, who started working for Votaw in late 1959 in the newly formed Satellite Techniques Branch (STB).¹¹ Wilhelm grew up in Yonkers, New York, earned a degree in electrical engineering from Purdue University in Indiana, and worked on classified submarine electronic development at a Chicago engineering firm before joining NRL to work initially on radio-based IFF (Identification Friend or Foe) systems for preventing friendly fire in battle situations.¹² When Wilhelm heard from a friend at the lab who had moved from the IFF group to the new Satellite Techniques Branch that STB was hiring, he let Votaw know he was interested.

“I felt kind of bad about it, you know. I'd only been with the IFF group for—what would it have been?—about six months. But the chance of working on a satellite just absolutely blew me away,” Wilhelm said.¹³ It would turn out that hiring Wilhelm would be the most important managerial act at NRL for Votaw, who in 1962 left the lab for a top position in the nascent commercial communications satellite business.

Wilhelm would become part of just about every vision and technical step that NRL's space technologists would take for the next half-century and then some. He would become one of the most decorated engineers and leaders in the country's non-civilian space program.¹⁴

To get the new branch off the ground, Votaw managed to scrounge up \$100,000. "There was still some residual hardware around that NASA had not scarfed up," recalled Wilhelm.¹⁵ A junior member of the branch, Wilhelm's first task was to build radio frequency transmitters for what became known as SOLRAD 1, NRL's first post-Vanguard scientific payload, whose mission was to measure solar radiation. It was a research goal snugly linked to Dr. A. Hoyt Taylor's and Dr. E. O. Hulburt's ionospheric studies in the 1920s and the ongoing science and technology challenges associated with long-distance communication.

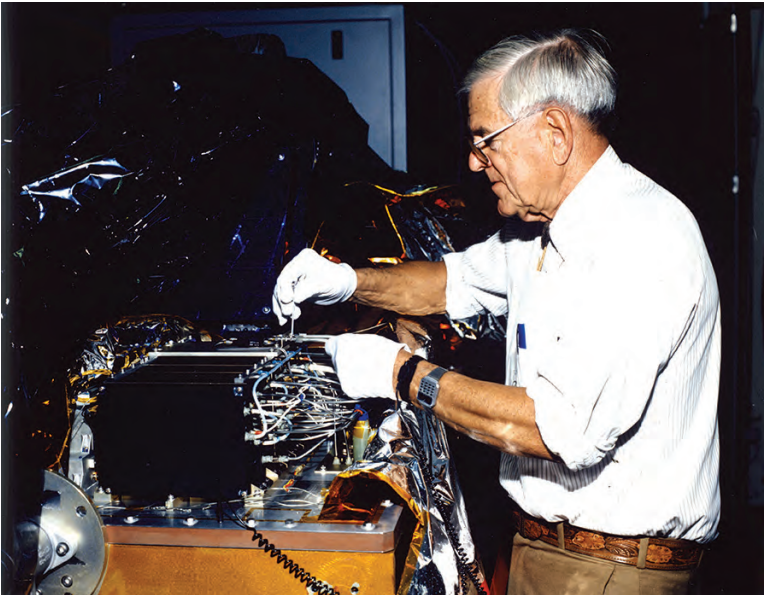
Besides Votaw and Wilhelm, there were a handful of others in the new branch that comprised NRL's post-Vanguard resurrection in the field of satellite engineering. Among them was Ed Dix, much more mild mannered than Votaw. Wilhelm described Dix as "the technical leader of the group" and from whom he had learned more about satellite design than anyone else. Sam Shover, an RF technician, was among the pioneers, as was Vance Winfrey, "an antenna guy," according to Wilhelm. There were several technicians who specialized in telemetry components that kept track of the satellite's condition and the measurements it was making and broadcast these to receiving antennas on the ground. "We had an electrical power systems guy named Joe Yuen who took care of the solar cells and batteries," recalled Wilhelm, and a "mechanical guy" who worried about the satellites' structures and how they attached to the booster.¹⁶

Also in on the satellite adventure from the get-go were master technicians Vince Rose and Ed Becke who together could build, or would know how to acquire, just about any component a radio frequency engineer could imagine or want. Becke never stopped coming to the lab and only his death, in 2013 at the age of 90, ended his life-long involvement with NRL's history in space. From the start, Rose and Becke worked with their NRL colleagues on missions to measure the characteristics of space and to calibrate the nation's space surveillance system (the one that started with the Vanguard program's Minitrack system). And they also would work with electronic countermeasures giant Howard Lorenzen to initiate a deeply secret program that would provide national leadership with space-based "national technical means" for gathering otherwise inaccessible information about the Soviet Union's military assets and capabilities.

The first project of NRL's regenerating space science group—SOLRAD 1—proved to be a good omen. The satellite's name is a contraction of the phrase "solar radiation." On June 22, 1960, the NRL SOLRAD satellite and a navigation satellite called Transit, built by the Johns Hopkins University's Applied Physics Laboratory, sat together within the fairing at the top of a Thor Able Star rocket. That rocket successfully ferried



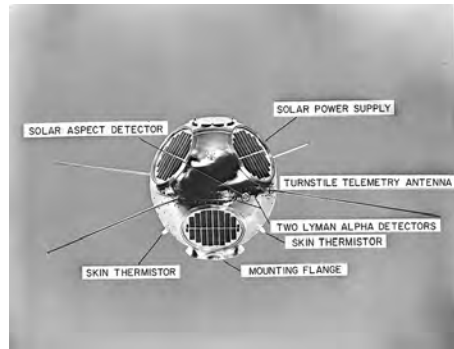
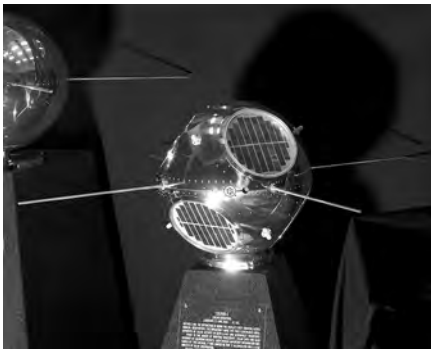
The Originals. A photo taken in 1958 or 1959 shows the group of NRL engineers who began rebuilding a space technology capability after the entire staff of Project Vanguard transferred to the brand new civilian space program with the creation of NASA. Standing leftmost is the first head of the Satellite Techniques Branch, Martin J. Votaw, who would be succeeded in that role in the early 1960s by Edgar L. Dix (fourth from right), who at the time of the photo was head of the Systems Design Section. Next to Votaw is Louis T. Ratcliffe, head of the Structures Design Section. Next to Ratcliffe is Ground Instrumentation Technician Phillip R. McRay. To Dix's right is SOLRAD Technician Paul Lester (of the Atmosphere and Astrophysics Division), then Structures Technician Roy A. Harding. Among the others in the photo is Telemetry Systems Section Head Gordon Van Loo. (NRL photo GRABGroup.jpg)



Longest Timer. Ed Becke, shown here in 2009, joined NRL during World War II. His service, as a skilled and versatile technician with expertise in antenna design, spanned more than half a century. (NRL photo Becke.jpg)

the two satellites into orbit where SOLRAD 1, for the next 10 months, telemetered data about the sun to NRL scientists. This achievement of a dual launch was simultaneously a birth of satellite-based navigation, a technology that NRL also would soon get into in the biggest way possible, and an optimistic rebirth for the contingent of solar scientists that NRL still had on its roster. Because the SOLRAD satellite carried sensors for measuring both X-rays and ultraviolet radiation (including Lyman-alpha radiation), the data harvest enabled lead scientist Herbert Friedman and his colleagues to confirm his theory that X-radiation, not ultraviolet radiation, was the form of solar radiation responsible for activating the ionosphere in ways that caused radio fade-outs.¹⁷

There was also a third mission on that flight. It was top secret and hidden within the very same shell that housed SOLRAD 1. It was so secret that Howard Lorenzen and his team in the Countermeasures Branch that was behind the mission could not even talk to the SOLRAD scientists about it. Wilhelm only learned about the hidden payload a month after he began working in the Satellite Techniques Branch on a transmitter he assumed was devoted to the SOLRAD payload. In a “screen room” normally used to prevent external RF signals from leaking inside during sensitive measurements, Votaw and several others in the STB revealed to Wilhelm, in his words, “a second payload that I had no idea about. And I had been working there on the same floor. I mean the security was incredibly good.”¹⁸



SOLRAD 1. In Building 222 on the NRL campus is an exhibit hall that houses models of a dozen or so satellites built and operated by NRL's space technologists. Shown here is an engineering model of SOLRAD 1, which hosted in the same shell the classified electronic intelligence payload known as GRAB 1. The scientific payload made the first continuous measurements of both X-rays and ultraviolet radiation reaching the Earth from the sun. Data accrued from six months of observation contributed to a better understanding of the sun and its effect on the Earth's ionosphere and on high frequency communication. The labeled image indicates major components of SOLRAD 1. (NRL photos 77112(6).jpg and 60407.jpg)

The STB engineers working on this classified payload kept it secret even from their space sciences colleagues working on the SOLRAD experiment. “They actually prohibited the countermeasures people from going across the mall [of the NRL campus] in daylight to the place where the satellites were being built,” noted Reid Mayo, whom Lorenzen had hired a decade earlier. “We had to go over there at night time and

get the shell and bring it over to the roof of our building and run antenna patterns, and so on, in the dark on the top of our building.”¹⁹

In the classified world, this payload was associated by several nomenclatures, but GRAB, short for Galactic Radiation Background experiment, became the most-used code name.²⁰ Canes, another code word associated with the program, referred primarily to the security and classification framework by which project insiders had to abide to keep everything secret, but it was confusingly used at times in reference to the payload too. GRAB featured a proof-of-concept orbiting sensor designed to detect and characterize defense radar systems deep in the heartland of the Soviet Union. This payload, to become known as GRAB 1, would become the world’s first spy satellite.²¹ As a young engineer on the project, Wilhelm recalled that he had never even heard the term “Canes.” “To those of us actually working on the satellite, it was just, you know, ‘Keep your mouth shut,’” he said.²²

The origin of this hush-hush program resided in a visionary document authored by several dozen NRL scientists and engineers. On December 10, 1957, only four days after Project Vanguard’s satellite-topped TV-3 rocket exploded in front of millions of observers watching the launch on live TV, the laboratory published the secret, 121-page report. It was designated as “NRL Report 5097” and titled “A Satellite and Space Vehicle Program for the Next Steps Beyond the Present Vanguard Program.” The report, which was declassified in 2001, amounted to a compilation of thought, intention, and engineering imagination that would secure for the laboratory a critical role in the U.S. space program even as it would undergo a massive change in the following year when NASA was created and began to operate.



Beyond Vanguard. Cover page of a pivotal report, 5097, that outlines NRL’s own vision of its role in the advent of the Space Age. The 1957 report was declassified in 2001. (NRL photo [BeyondVanguard-1.pdf](#))

“The present Project Vanguard IGY Satellite Program is expected to be completed during the latter half of 1958,” the document states in its opening, stressing that none of the Vanguard satellites for the IGY will “include any military equipment, per se.” And yet, the document continues, “recent thinking, stimulated in part by the Soviet satellites, has brought into focus the fact that there are a number of very important military and operational applications of satellites which must be exploited if the Nation’s relative military position is not to be seriously impaired.”²³

Despite appearances, the timing of NRL Report 5097 with respect to the Vanguard explosion on December 6, 1957, was fortuitous. Under the guidance of Vanguard chief John Hagen, a total of 53 NRL staff had previously prepared contributions for a forward-looking manifesto of sorts, which amounted to NRL’s vision for “America’s space program beyond Vanguard,” according to a once-secret history of the nation’s first electronic intelligence, or ELINT, satellite programs.²⁴ (ELINT refers to “information derived from electronic signals that do not contain speech or text,” whereas interception of signals that do contain speech and text goes under the rubric of communications intelligence, or COMINT.²⁵ COMINT and ELINT combined can go under the larger category of signals intelligence, or SIGINT.)

With an eye toward securing funding so the lab could pursue the spaceward vision articulated in Report 5097, which included a far-reaching compilation of recommendations for national satellite and space vehicle programs, Dr. Louis Gebhard, Superintendent of the Radio Division, delivered a copy to the Navy’s Bureau of Ordnance on December 24, 1957. At this time, the Navy bureaus were the primary sponsors for and funders of NRL research and development work. The most developed space-based intelligence-gathering concept in the report, primarily from Lorenzen, was a reconnaissance package designed to characterize a radar system deployed around “the Moscow defense complex” and that was “out of range for ground-based sites and conventional airborne platforms.”²⁶ A month later, Captain Peter H. Horn, NRL’s Commanding Officer at the time, forwarded the report to the Chief of Naval Operations (CNO), Admiral Arleigh Burke, who early on discerned how important the newly accessible realm of space would be for naval operations. From there, the report underwent review in the top echelons of military and civilian leadership, straight up to President Eisenhower.

On January 31, 1958, nine days after the review and approval process for NRL Report 5097 had gotten under way, the Army launched Explorer 1, the first U.S. satellite to make it into orbit after the Soviet Union’s successes with Sputniks 1 and 2. In addition to shoring up the country’s listing confidence in the wake of the Soviet Union’s firsts in the space race, the Explorer mission was a fast scientific success. Data from this mission would help Dr. James Van Allen of the University of Iowa discover the radiation belts around the Earth that would be named after him.

Although nothing would assuage the emotional weight that the high-profile launch failure of the TV-3 Vanguard rocket in early December had placed on the shoulders of NRL's Vanguard team, Explorer 1 carried with it a vindication of sorts—and one unknown to most—for the NRL engineers and space scientists. Within the 31-pound, bullet-shaped satellite was a cylindrical, 20-pound “Vanguard instrumentation package,” a miniaturized telemetry module²⁷ that NRL had transferred to the Jet Propulsion Laboratory in Pasadena where Explorer 1 was being readied for integration into the booster. Then swiftly came a bitter chaser for the NRL team. Five days after the Explorer 1 launch, the second attempt by NRL to launch a Vanguard satellite failed one minute after launch, this time due to a glitch in the control system.²⁸

In this time of both promise and frustration, and of growing Cold War angst, the laboratory's vision of its future in the just-born Space Age was circulating among the highest strata of Navy leadership and from there within the top tiers of military, intelligence, and civilian government decision makers. It was a time when the absence of reliable information about the military capabilities of the Soviet Union begat worst-case scenarios that could not be refuted by evidence, because so little hard data was in hand. “Military and intelligence potential of space-based systems quickly gained appreciation in the DoD,” according to naval-officer-turned-historian Ronald Potts, referring to systems like those proposed by Lorenzen and his team. “Study efforts became projects,”²⁹ observed Potts, who also had personal experience in the data analysis side of NRL's early ELINT satellites.

The institutional and programmatic infrastructure for supporting and expediting this space-directed ambition was getting installed. Just weeks after that second attempt to launch a Vanguard satellite failed on February 5, 1958, for example, the Advanced Research Projects Agency (known now as the Defense Advanced Research Projects Agency, or DARPA) was established to coordinate and oversee space-related research and development throughout the defense sector. Among the initial actions of ARPA was to continue development of the Army's Explorer program and to fully back a top secret, camera-based reconnaissance program. Proposed by the Air Force and known initially as the Sentry Program—though the code name Corona is the one that would stick the most—it would entail the mid-air retrieval of canisters of film ejected back through the atmosphere from the camera-carrying satellites.³⁰ Among the players who were pushing camera and film technology to new limits were Edwin Land (inventor of the Polaroid camera and its self-developing film system) and Kodak, the camera and film company. This was an era of technological audacity and a readiness to support that audacity with taxpayers' money.

Amidst the full sprint to more high-tech means for gathering intelligence about the Soviet Union's military capabilities and operations, the Navy's Bureau of Aeronautics, or BuAer (whose Avionics division specified electronic countermeasures, or ECM, requirements for the fleet³¹), sent a confidential letter on March 5, 1958, to NRL. This same day, another Army attempt to put an Explorer satellite into orbit

failed. The letter called on the lab “to design, develop and fabricate an Electronic Counter-measures System, subminiaturized, lightweight, for supersonic vehicles,” a category that includes rockets and advanced aircraft. This call for new technology superseded a related long-term project for early warning aircraft that the lab had been pursuing, a sign of how priorities were shifting toward space.³²

Specifications for the system included an intercept receiver for a frequency range from 50 megahertz (high frequency) to the thousand-fold-higher frequency of 50 gigahertz (“extremely high frequency”), an ability to function on both manned and unmanned vehicles, and a telemetry system for automatically transmitting intercepted signals to existing naval receiving stations. The high-priority request from BuAer instantly raised Lorenzen’s Countermeasures Branch to an even more privileged place at the lab than it already enjoyed. And the branch got busy. “Intercept equipment developed by the branch included antennas and receivers, recorders, and analysis devices,” Potts noted, referring to the lab’s non-space work. “These equipments were often upgraded to exploit new technology and keep pace with the threat signal environment as it spread into higher regions of the radio frequency spectrum. Several generations of signal direction finding (DF) equipment had been developed for shore stations, ships, and aircraft, including long-range patrol planes and electronic signal ferrets.”³³ (Here, the term ferrets refers to airborne missions that would deliberately fly near or over adversaries’ borders to provoke the activation of radar equipment, which receivers on the aircraft could then intercept for later analysis.)

Taking in all of this talk and planning about space-based ELINT technology was the Secretary of the Air Force, Donald Quarles, who in the summer of 1955 had assumed the responsibility of assembling and implementing a national ELINT program. Quarles had done radar development work previously when he worked on military electronic systems at Bell Laboratories.³⁴ Confidence that such a program was worth pursuing was due, in part, to the technical advancements that Lorenzen and his electronic countermeasures team had made since the end of World War II. “By 1955, magnetic drum and magnetic tape recording technology and protocol had advanced to the point that electromagnetic signals of interest could be preserved on tape and then analyzed elsewhere in detail after the collection event,” Potts recounted.³⁵ This progress in recording technology provided the means to tease out a Soviet radar “order of battle.” That, in turn, supplied important intelligence for the Strategic Air Command (SAC), whose long-range bombers would have to follow survivable routes as they carried their nuclear bombs to targets in the Soviet Union in the event that World War III had been triggered.

Illustrative of the increasing value that ELINT was gaining in military circles was the establishment in 1957 of the National Technical Processing Center (NTPC) and its co-location with the ELINT-centered Naval Security Group on Nebraska Avenue in northwest Washington, DC, near the campus of American University.³⁶ There, a staff of about 100 personnel from the Army, Navy, Air Force, and CIA formulated the

“objectives and general intelligence requirements”³⁷ for the nation’s overall ELINT program, which, if approved by the Joint Chiefs of Staff, would then serve in the field as guidance for signals collection by ECM-equipped operational forces.

NRL’s Countermeasures Branch participated in and supported the national ELINT program by serving on technical committees; developing intercept equipment; evaluating data acquired from ECM configurations installed on Navy, Air Force, and CIA platforms; and technically supporting the NTPC, Potts noted.³⁸ All this involvement by NRL had Lorenzen to thank for it.

A significant factor that contributed to NRL’s pioneering role in the development of ELINT satellites derived from Lorenzen’s wartime contacts with the British Admiralty through which he was able to procure captured German electronic equipment. One of these pieces of equipment, the Athos system, included a crystal whose electrons responded to weak probing radar signals and then converted these into discernible electronic signals. German lookouts on submarines had relied on Athos detectors to pick up airborne radar signals at wavelengths of 10 centimeters and 3 centimeters, which are on the short side of the radio frequency spectrum.

At the time, Mayo had been developing crystal-based receiver technology for airborne and shipborne electronic countermeasures applications. And in 1957 he was using the captured Athos crystal receivers as his point of departure for designing systems that could detect new higher-frequency signals from Soviet radars.³⁹ Mayo’s systems featured a so-called wide-open receiver that, Mayo later pointed out, “looks at all frequencies that are capable of being detected by the antenna.”⁴⁰ As such, they were well suited for determining what radar and other electromagnetic signals were out there on the airwaves, from either known or unknown sources.

Another piece of captured German hardware that proved pivotal for the design of NRL’s ELINT satellites was a device for precisely measuring the angle of incoming RF signals. Known as a Wullenweber goniometer, it ended up in a shack at the center of an array of antenna elements that formed into a circle with a diameter of 400 feet.⁴¹ The array was located on the Hybla Valley Coast Guard Communication Station near Mt. Vernon, Virginia, only a 30-minute drive from downtown Washington, DC. The goniometer “combined the signals from a subset of the antennas to produce a high-gain beam that rejected interfering signals from directions other than that of the signal of interest,” explained Dr. Bruce Wald, whom Lorenzen had hired into the Countermeasures Branch in 1953 and who would become one of the lab’s most brilliant researchers and early computer programmers, working mostly on classified programs.⁴² With the goniometer in place, Lorenzen and his colleagues were convinced it would be possible to accurately determine the angle at which shipborne emitters at sea were sending out high frequency radio signals.

As the NRL electronic countermeasures team was working to move this concept forward, the Soviets placed Sputnik 1 into orbit where its radio beacon sent out pulses at 20 megahertz for the entire world to listen in on. Those around the coun-

try who were part of the effort to launch a satellite, under the auspices of the global International Geophysical Year collaboration, or who were part of the military effort to develop ballistic missiles, also were in the business of tracking rocket-powered projectiles. Mayo and several others in the DF (direction finding) section of the Countermeasures Branch were diverted to the task of repurposing the Hybla Valley DF installation so that it could track Sputnik and determine its trajectory. Rather than seeking out Soviet aircraft and ships, the installation suddenly was in the brand new business of seeking out an orbiting satellite.



Huff-Duff. Known formally as a Wide-Aperture Circularly Disposed High Frequency Radio Direction Finder, this array of antennas and processing equipment in the central building is capable of identifying the direction from which high-frequency radio signals are emanating. This array, used by NRL in the late 1950s and 1960s, was located at Hybla Valley, Virginia, not far from Washington, DC. (NRL photo 58-039971.jpg, 58-040249.jpg, or 60-45951(1).jpg)

“It was a very exciting time when Sputnik went [up],” Mayo recalled. “Everyone was excited by it, and the talk about space was everywhere—everyone was trying to get up to speed. I was anxious to think of how we could do other things from space ... the opportunity of a wide-open system being useful to look into the heartland of the Soviet Union was pretty obvious.”⁴³

In addition to the crystal detectors and the direction finding system, there was a third key technical influence directing the NRLers toward the invention of an orbiting ELINT platform. Just two months after the first Sputnik launch, Mayo and his assistant Vince Rose, an antenna expert, were diverted yet again, this time by a countermeasures group within the Navy’s Bureau of Ships, to modify a periscope-mounted system that could detect radar signals in the periscope’s line of sight.

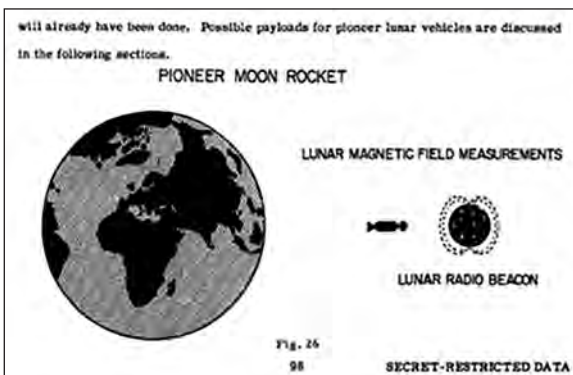
“The submarine service had us install a small spiral antenna inside the top of the periscope, inside the glass of the periscope, and affixed to that antenna was a small diode detector,” Mayo recalled. “It allowed the submarine skipper to have an electromagnetic ear above the surface, as well as an eye.”⁴⁴ To pull this off, Mayo and Rose worked closely with the Maine-based periscope manufacturer, Kolmorgen Optical, and then oversaw the installation and testing of the equipment on a submarine. The vessel was scheduled for a mid-January deployment after which it would participate

in DF tasks at sea. Mayo and Rose did the same for subsequent submarine deployments in February and March.

While Mayo engineered the submarine ECM device, Lorenzen and his boss, Louis Gebhard, were promoting space-related applications of the crystal-based detection technology.⁴⁵ Their deliberations became the basis for a key, seven-page portion of NRL's Report 5097 about its post-Vanguard vision.⁴⁶ The section described what would become the world's first electronic reconnaissance satellite. In ways that only he could, Lorenzen tapped into back channels to secure support and the necessary high-priority "problem request" from a sponsor. That came through when an electronic countermeasures expert at the Bureau of Aeronautics called for Lorenzen's group to move the satellite concept that the lab had outlined in Report 5097 toward concrete plans for producing hardware.

The full 121-page "Beyond Vanguard" report laid out an ambitious and comprehensive program that could only emerge from the minds of engineers driven by the excitement of rocket technology, the urgency of Cold War tension when another Pearl Harbor could mean a surprise attack with nuclear bombs, and the hands-on experience with actual rocketry and rocket-borne science they had been acquiring, first with V-2s and then other rockets including the Aerobees, Vikings, and Vanguards. The report called for, among other ambitious goals, a rapid series of three upgrades of the Viking rockets leading to a booster that could ferry 1,500 pounds of payload into orbit; the development of launch operation protocols; military and operational satellite development; and improved satellite tracking and orbital determination abilities. The original plan in the report called for a fantastic launch schedule featuring some 42 satellite-topped rockets by April 1961.

In addition to discussing space-based scientific studies of biological, meteorological, geophysical, lunar, solar, interplanetary, and other phenomena, the report pointed to development of satellite techniques such as guidance, means for measuring satellite conditions during orbit, and procedures for recovering satellites (for manned missions, for example). It also outlined a raft of intelligence pursuits, among them electronic intelligence and reconnaissance associated with nuclear tests and missile



Moon Visions. Figure 26 of Report 5097, showing "Pioneer Moon Rocket" for making physical measurements of the moon. The report was declassified in 2001.

(NRL photo *BeyondVanguard-1.pdf*)

tests. TV, navigation, and communications roles were also on the list. One chapter of the report, titled “Pioneering Lunar Vehicles” envisioned “Earth to moon” vehicles that would measure the moon’s magnetic field, establish a lunar orbit, and even—in a nod toward Robert Goddard’s own visions almost 40 years earlier—smash into the moon in a manner that would be discernible and documentable from Earth.⁴⁷

For NRL, chapter two of the report would prove to be the most prescient part regarding the future place of the lab in the U.S. space program. First to move forward would be its plan for the world’s first ELINT satellite for identifying and characterizing adversaries’ radar installations. With precise-enough orbital determination calculations from the satellite tracking system, the report suggested, the proposed satellite would be able to provide “considerable information relative to the locations of the sources of the [radar] signals.”⁴⁸

There was more. Report 5097 also included a section in which the NRLers floated an early articulation of the fundamental geolocation-determining and navigational concept behind the present-day Global Positioning System, or GPS. “The theory of the determination of the position of an observer by means of zenith distance observations of artificial satellites is presented in this section,” the report stated. “The principal advantage of radio navigation by means of satellites lies in the fact that it enables one to take advantage of present-day techniques for measuring time with high accuracy.”⁴⁹

More than anyone else, Roger Easton, a physicist who began working in NRL’s Radio Division in 1943 on radar beacons and techniques for blind landing of aircraft,⁵⁰ would take on this mission in the coming years. Key among Easton’s accomplishments was to push the technology of atomic clocks to ever-higher regimes of timekeeping accuracy, which was a prerequisite to ever more accurate position determinations. He also was central in working out the theory and practice of the necessary communication between satellites and the people and objects whose positions are to be determined.

Also in that visionary chapter of Report 5097 were sections on detecting and characterizing details of nuclear weapons tests by the Soviet Union by way of satellite-borne detectors of heat, particulate emissions, and optical and other types of electromagnetic radiation. These proposed reconnaissance systems included memory and telemetry components that would enable the storage of data by satellites until they were within the line of sight of a receiving station such as the ones built for the Minitrack system. The NRL authors also described a system for detecting neutrons, that could differentiate a detonation of a nuclear device on the ground or in the atmosphere from one in space, where the attenuating effect of air on neutrons would be absent.

The report also described the potential of satellites to serve as relays or “repeaters” for communication circuits that span several thousand miles with the sender, satellite, and receiver forming the points of upwardly tilted triangles.

“Communications with submerged submarines are especially important,” the report noted at a time when the land, sea, and air triad of the nation’s nuclear strategy—the so-called Single Integrated Operational Plan (SIOP)—was under construction and deployment. “This is particularly true of atomic submarines which are capable of launching Polaris missiles carrying nuclear warheads. It is highly desirable that these submarines be capable of operating without the need for breaking the surface at all, even for the purpose of receiving orders to fire their Polaris missiles.”⁵¹ In 1960 and 1961, NRL dedicated a series of satellites, the Low Frequency Trans-Ionospheric (LOFTI) satellites, to the question of whether it indeed was technically feasible to communicate with submerged submarines via satellite—particularly nuclear-weapons-carrying subs underneath the Arctic ice—using very low frequency radio waves, which were known to penetrate seawater’s RF-swallowing tendencies.⁵² The submarine communication issue involved such details as the angular inclinations of the polar orbits that would cover the relevant oceanic regions and the number of satellites required for the minimal communication times.

The NRL satellite planners, with such strong representation from the lab’s electronic countermeasures experts, were well aware that satellites, although flying much higher than any other military assets in the past, still would be vulnerable to sophisticated electronic warfare threats and so included this concern in the report. Of utmost importance with any communication with a submarine carrying nuclear weapons, they noted, is security and reliability, especially in the highly tense contexts of the Cold War.⁵³

“Conventional jamming may take the form of interfering with submarine reception by flying jammer transmitters over the Arctic areas known to be of interest,” the report warned. “These might be borne by planes or high-altitude balloons. The only basic defenses against this type of interference are to change frequency—considered impracticable with present satellite limitations—to increase the transmitter power, or to use directional antennas aboard the submarine. This latter course appears to be the only feasible one.”⁵⁴

“Another type of jamming might be to jam the satellite receiver at the time of loading,” the report added. “This must be done from ships, bases, or planes within range of the satellite. Unfortunately, in assuming a loading zone reaching 1000 miles east from Boston, a similar jamming zone exists an additional 1000 miles to the east for the same satellite at the same time. This area includes some portions of Europe and European coastal waters. Again, the only real defense lies in increased transmitter power, this time of the shore-based terminal. Directional transmitting antennas [whose narrow beams are harder to jam] are indicated.”⁵⁵

Spoofing, or the enemy’s insertion of false or altered messages in communication circuits, was also on the list of worries. “The defense against this type of attack would appear to lie in providing the satellite receiver with enough intelligence to tell

a false from a true message,” the report writers argued. “No security system of this sort exists, as far as is known, but some thought has been given to the same problem for another project, and it is believed that a method can be devised based on storing ‘unlocking’ codes in the satellite which must be received correctly before a message is accepted for retransmission.”

The mark of Lorenzen was most apparent in the report’s section titled “Electronic Reconnaissance Intelligence Satellite.”⁵⁶ “To be effective the satellite must, of course, have an orbit that passes over the target or at least comes within line-of-sight of it,” the report stated, referring to missions to detect and characterize Soviet radar systems. “The target of prime importance is in the Moscow complex,” where intelligence reports using more conventional means had been indicating the possible construction of anti-ballistic and anti-aircraft radar systems, as well as missile and atomic testing facilities.⁵⁷ “The reception of the intelligence transmission from the proposed satellite could be accomplished from several sites. A most important fact: these receiving sites are already existent and would require a minimum of additional equipment and manpower,” the report noted, referring to the receiving stations of the Minitrack system and likely elsewhere.⁵⁸

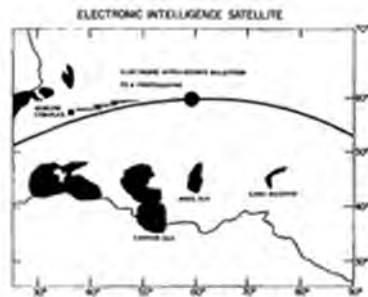


Fig. 22

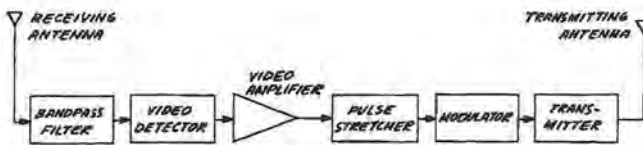


Fig. 9 - Satellite electronic reconnaissance system

Electronic Snooping. Figure 9, page 33, of Report 5097 shows a schematic of a “satellite electronic reconnaissance system,” and figure 22 on page 95 shows the trajectory of a proposed electronic intelligence satellite. (NRL photo *BeyondVanguard-1.pdf*)

This same section of the “Beyond Vanguard” report goes into some technical detail about the actual radar-snooping technology, which was based closely on the high-frequency direction-finding systems and techniques that Lorenzen’s group had developed during World War II and had greatly improved since then. Said the report, “The system utilizes a microwave antenna, a bandpass filter, a crystal detector, a simple video amplifier, a pulse stretcher circuit, a modulator, a tiny transmitter, and

a telemetering antenna. Most of these components are now available in countermeasures equipment.”⁵⁹

It is easy to imagine Lorenzen typing out these words: “In conclusion, it is possible with well-known proved circuits and available components to build an Electronic Intelligence Reconnaissance Satellite capable of telemetering information from and about the Moscow defense complex to existing U. S. stations. The first device would operate on selected prime targets, would weigh less than 5 pounds, and would have an operational life of 3 weeks ... It is estimated that a satellite of the type described above could be readied for flight testing within about a year, assuming that appropriate priorities would be assigned. Equipment for succeeding vehicles could be readied at the rate of about one per month.” The voice of the report featured the nonchalant bravado of can-do engineers who already know their expertise in the invisible realm of electromagnetism had resulted in many significant contributions to the nation’s defense.⁶⁰

Lorenzen’s appreciation and demand for secrecy, as well as the high-level connections he forged for the lab, come through in full force in the report. “The project outlined would require the highest possible security control and safeguards. This project has been discussed in detail with the cognizant personnel in the Office of the Director of Naval Intelligence. The requirements for such a program have been discussed and are being made the subject of official correspondence. This program would have one of the highest priorities assigned by the intelligence communities.”⁶¹

In the report, the NRL satellite visionaries also describe space-based techniques for more general reconnaissance, not just of the Moscow complex. “An earth-encircling satellite would provide a means of electronic intercept over otherwise inaccessible territories of potential enemies. The satellite would be equipped with an intercept receiver and an electronic memory to permit recording of intercepted signals and subsequent retransmission of these signals by a radio transmitter aboard the satellite. The memory would be arranged to receive instructions through ground command transmissions. These instructions would activate the intercept function over enemy territory and the retransmission and command acceptance functions over friendly territory on a time basis, thus preventing the enemy from detecting the presence of the satellite and of interfering with its operation.”⁶² The NRL designers were considering worst-case scenarios also: “Explosive charges could be arranged to assure destruction of the satellite upon its return to earth either after performing its mission or in case of launching failure. A potential enemy thus could learn little about it through possible recovery of its parts.”⁶³

ELINT is what these satellites were all about, as opposed to IMINT, or imagery intelligence, which the Air Force had begun working on in its Sentry (Corona) photoreconnaissance program, or HUMINT, which refers to the more traditional human intelligence, the feet-on-the-ground, in-person sort of spying. It would not take long before NRL’s on-paper ELINT satellite laid out in the report would take a leap

toward realization. But it would take a Herculean effort of persuasion at the highest levels of government to open the pathway.

¹ Public Law 85-568, the National Aeronautics and Space Act of 1958.

² Lane E. Wallace, *Dreams, Hopes, Realities: NASA's Goddard Space Flight Center, The First Forty Years* (Washington, DC: National Aeronautics and Space Administration, 1999), pp. 18–19.

³ The Beltsville Space Center was renamed as the Goddard Space Flight Center on May 1, 1959, in honor of Robert H. Goddard, the American rocketry pioneer who sparked Louis Gebhard's dreams of rocket-based science.

⁴ Wallace, *Dreams, Hopes, Realities*, pp. 18–19.

⁵ The transfer was specified in Executive Order 10783 by the President on October 1, 1958.

⁶ William Corliss, *Histories of the Space Tracking And Data Acquisition Network (STADAN), the Manned Space Flight Network (MSFN), and the NASA Communications Network (NASCOM)*, (Washington, DC: National Aeronautics and Space Administration, 1974), pp. 4–68; William Corliss, *NASA Sounding Rockets 1958–1968, A Historical Summary (SP 4401)*, (Washington, DC: National Aeronautics and Space Administration, 1971), pp. 35–40.

⁷ See, for example, John Hagen, “Vanguard—The Laboratory Ventures Into Space,” in *NRL Progress* (Washington DC: Naval Research Laboratory, 1973), p. 31; and “The U.S. Naval Research Laboratory (1923–2005) Fulfilling the Roosevelts’ Vision for American Naval Power,” NRL/MR/1001--06-8951 (Washington, DC: Naval Research Laboratory, March 6, 2006), p. 26.

⁸ <http://www.nrl.navy.mil/ssdd/ncst>.

⁹ <http://www.nrl.navy.mil/ssdd/ncst>.

¹⁰ Press release, Naval Research Laboratory, August 28, 1962.

¹¹ Peter Wilhelm, interview with author, 1997; Ivan Amato, *Pushing the Horizon: Seventy-Five Years of High Stakes Research and Technology at the Naval Research Laboratory* (Washington, DC: Naval Research Laboratory, 1998), pp. 198–199.

¹² Wilhelm, interview with author, 1997.

¹³ Peter Wilhelm, interview with NRL Historian Leo Slater, August 7, 2009.

¹⁴ Peter Wilhelm has received the following honors and awards, among others: Pioneer of National Reconnaissance, 2000; Presidential Distinguished Rank Award, 1999; AIAA Goddard Astronautics Award, 1999; The Secretary of the Navy Career Service Award, 1999; Department of Defense Distinguished Civilian Service Award, 1998; NRL Lifetime Achievement Award, 1998; National Academy of Engineering, 1997; NRL's Roger L. Easton Award for Engineering, 1997; Rotary National “Award for Space Achievement” Foundations Stellar Award for Program Management, 1993; Robert J. Collier Award (Team Award), 1992; Elected a Fellow of AIAA, 1989; Presidential Rank Award, Meritorious Executive, 1988; Captain Robert Dexter Conrad Medal (Navy's highest award for scientific achievement), 1987; E.O. Hulburt Award (NRL's highest award for science; the first and only engineer to win this award), 1983; Navy's Space Systems Program Achievement Award, 1985; IEEE Aerospace and Electronic Systems Group “Man-of-the-Year Award,” 1981; Federal SES Performance Awards, 1983, 1984, 1985, 1986, and 1994; Navy Meritorious Unit Commendation for Development, Acquisition and Operation of Space Systems, 1977 to 1981; Elected Fellow of Washington Academy of Sciences, 1971; Navy Award of Merit and Special Achievement, 1976; Navy Unit Commendation for Exceptional Meritorious Service, 1974 to 1976; Navy Distinguished Civilian Service Award, 1971; and Navy Meritorious Civilian Service Award, 1962. See more at: <http://www.nrl.navy.mil/media/news-releases/2009/nrls-peter-wilhelm-marks-50-years-of-government-service#sthash.ngY2u7Dl.dpuf>.

¹⁵ Wilhelm, interview with author, 1997.

¹⁶ Peter Wilhelm, interview with NRL Historian David van Keuren and Dean Bundy at the Naval Center for Space Technology on November 19, 1987.

¹⁷ T. Chubb, H. Friedman, R.W. Kreplin, W.A. Nichols, A.E. Unzicker, and M.J. Votaw, “Results from the NRL Solar Radiation Satellite,” in *Space Research II*, H.C. Van de Hulst et al., eds. (Amsterdam: North Holland Publishing Company, 1961); <http://code8100.nrl.navy.mil/about/NCST/index.htm>.

¹⁸ Peter Wilhelm, quoted from NRL-produced video, “GRAB—NRL’s Secret Success in Space,” released in 1998 when GRAB was declassified.

¹⁹ Reid Mayo, quoted from NRL-produced video, “GRAB—NRL’s Secret Success in Space.”

²⁰ For an account of various nomenclatures, see Robert A. McDonald and Sharon K. Morena, *Raising the Periscope... GRAB and Poppy: America’s Early ELINT Satellites* (Chantilly, VA: Center for the Study of National Reconnaissance, National Reconnaissance Office, September 2005).

²¹ Ronald L. Potts, *U.S. Navy/NRO Program C Electronic Intelligence Satellites (1957–1977)*, LEO Systems Program Office, National Reconnaissance Office, September 3, 1988, declassified with redactions and approved for release from NRO on June 13, 2012.

²² Wilhelm, interview with Slater, August 7, 2009.

²³ NRL Report 5097, “A Satellite and Space Vehicle Program for the Next Steps Beyond the Present Vanguard Program,” December 10, 1957.

²⁴ Potts, *U.S. Navy/NRO Program C*, p. 3.

²⁵ National Security Agency, Cryptologic Almanac 50th Anniversary Series, http://www.nsa.gov/public_info/_files/crypto_almanac_50th/six_decades_of_second_party_relations.pdf.

²⁶ NRL Report 5097, P.W. Binning and J.W. Middour, “A Brief History of NRL’s Early First in Spaceflight,” *Advances in the Astronautical Sciences* 129 (2008): 1233–1250.

²⁷ Whitney Mathews, “Telemetry from Explorer,” *Electronic Industries* 17 no. 5 (March 1958): 58–59.

²⁸ Potts, *U.S. Navy/NRO Program C*, pp. 2–3.

²⁹ Potts, pp. 2–3.

³⁰ See, for example, Dwayne A. Day, John M. Logsdon, and Brian Latell, eds., *Eye in the Sky: The Story of the Corona Spy Satellites* (Washington, DC: Smithsonian Institution Press, 1998).

³¹ Its charge did not include shipborne-associated ECM requirements.

³² Potts, *U.S. Navy/NRO Program C*, p. 4.

³³ Potts, p. 4.

³⁴ Potts, p. 7.

³⁵ Potts, p. 6.

³⁶ This organization formed from a precursor body known as the Army-Navy Electronics Evaluation Group, or ANEEG.

³⁷ Potts, *U.S. Navy/NRO Program C*, p. 7.

³⁸ Potts, *U.S. Navy/NRO Program C*, p. 7; McDonald and Morena, *Raising the Periscope*, p. 132.

³⁹ Reid Mayo, in *Beyond Expectations—Building an American National Reconnaissance Capability: Recollections of the Pioneers and Founders of National Reconnaissance* (Bethesda, MD: National Reconnaissance Office and the American Society for Photogrammetry and Remote Sensing, 2002), p. 132; Potts, *U.S. Navy/NRO Program C*, p. 7.

⁴⁰ McDonald and Morena, *Raising the Periscope*, p. 132.

⁴¹ Bruce Wald, unpublished memoir shared with the author, p. 11.

⁴² Wald memoir, p. 11.

⁴³ Peter Wilhelm, quoted from NRL-produced video, “GRAB—NRL’s Secret Success in Space,” released in 1998 when GRAB was declassified.

⁴⁴ Peter Wilhelm, quoted from NRL-produced video, “GRAB—NRL’s Secret Success in Space,” released in 1998 when GRAB was declassified.

⁴⁵ Potts, *U.S. Navy/NRO Program C*, p. 12.

⁴⁶ NRL Report 5097.

⁴⁷ NRL Report 5097, pp. 98–103.

⁴⁸ NRL Report 5097, p. 37.

⁴⁹ NRL Report 5097, p. 12.

⁵⁰ <http://www.nrl.navy.mil/media/news-releases/2005/president-announces-roger-easton-recipient-of-national-medal-of-technology>.

⁵¹ NRL Report 5097, pp. 39–45.

⁵² NRL Report 5097, pp. 39–42.

⁵³ NRL Report 5097, pp. 43–44.

⁵⁴ NRL Report 5097, p. 43.

⁵⁵ NRL Report 5097, p. 44.

⁵⁶ NRL Report 5097, pp. 32–38.

⁵⁷ NRL Report 5097, p. 92.

⁵⁸ NRL Report 5097, p. 32.

⁵⁹ NRL Report 5097, p. 33.

⁶⁰ NRL Report 5097, p. 35.

⁶¹ NRL Report 5097, p. 38.

⁶² NRL Report 5097, p. 36.

⁶³ NRL Report 5097, p. 38.

THE PRELUDE TO SPACE RECONNAISSANCE

It was during an early spring snowstorm in Pennsylvania that the technical insight underlying the actual hardware for a spy satellite came to Reid Mayo. After long hours and overseas duties related to the development and installation of new ship-board high frequency direction finding equipment, Mayo went on vacation in 1958 with his family to Grand Rapids, Michigan. On their return, a snowstorm stranded them at a Howard Johnson's along the Pennsylvania Turnpike. "While his wife and two children dozed, he began thinking about the work that awaited him upon his return to the NRL," National Reconnaissance Office historian Ronald Potts recounted in his once classified narrative of NRL's satellite ELINT programs.¹

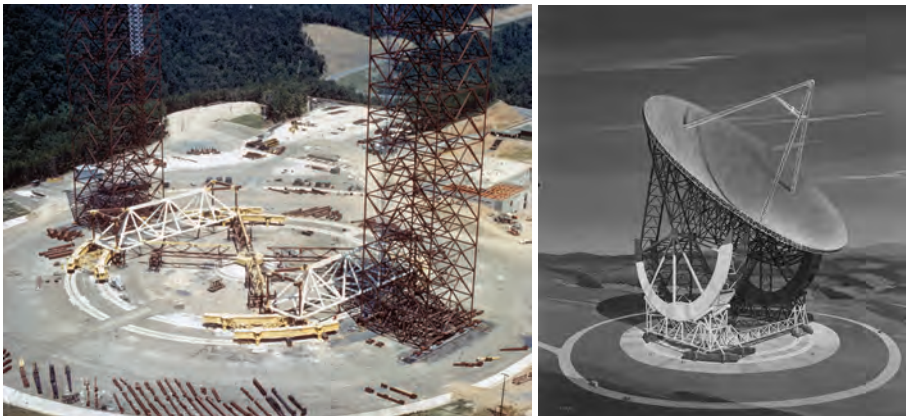
Churning in Mayo's mind was the periscope-mounted direction finding device problem (for the Bureau of Ships), which was two months from completion, and a couple of aircraft electronic countermeasures (ECM) problems to take care of. Also on his mind was Vanguard 1, which since March 17 had been circling overhead. As the snow fell outside the restaurant on March 28, Mayo sketched out on the back of a paper placemat preliminary diagrams and calculations to determine what it would actually take to be able to listen in on Soviet radar systems—among them air search radars NATO referred to as Gage and Token²—with intercept and relay equipment aboard an orbiting satellite several hundred miles overhead. That combination of mental ingredients baked into an idea that would help alter the course of intelligence-gathering technology, the lab, military and civilian decision making, and the course of the Cold War.

Recalled Mayo: "We thought there might be some benefit in raising the periscope just a little bit . . . maybe even to orbital altitude. So I did some calculations to see if truly we could intercept the signals. The calculations showed clearly you could get something, up to an altitude of 600 miles."³ Mayo realized from his calculations that if he could place the S-band (2 to 4 megahertz) portion of the early-warning ECM system he had designed for submarines onto an orbiting platform, it would be possible to, in his words, "gain access to air defense radars in the Soviet interior."⁴

Among the main questions such reconnaissance equipment could answer was whether the Soviet Union had deployed air defense radars in the country's interior that were different from the ones that ferret missions, involving aircraft that sometimes became exposed to lethal peril, already had detected within about 200 miles of the country's periphery.⁵ When Mayo got back to the lab, he immediately presented the Howard Johnson's placemat and his big idea to Howard Lorenzen, his supervisor

and head of the Countermeasures Branch. An all-important detail: with enough miniaturization, an S-band intercept receiver unit could fit into the shell of a 20-inch Vanguard satellite.⁶

Lorenzen could see this was doable, but he also knew it needed more development. To help, he tasked James Trexler, one of NRL's most audacious thinkers, to work out the space-collection task and capabilities in more detail. At the time, Trexler was working on one of the grandest and most outlandish, top-secret projects of the entire Cold War. Known as Project Moonbounce, the idea was to construct a magnificent radar dish as tall as the Washington Monument and with a collection area of more than seven acres. It was to be mounted on a massive turntable so that it would be steerable from horizon to horizon. Build this "big ear" in a radio-quiet region of West Virginia, Trexler had calculated, and it would be possible to intercept radar and radio signals bouncing off the moon from the heartland of the Soviet Union, at least for a few minutes each day. It was a ground-based approach to the sort of intercepts that Mayo had in mind with his satellite proposal.⁷



The Big Ear. In a show of the desperate Cold War desire for information about the Soviet Union, NRL engineer James H. Trexler conceived of a gargantuan, 600-foot-diameter, steerable receiving antenna (right image) that could pick up signals originating in the Soviet Union that would bounce off of the moon into the antenna's seven acres of reception area. Construction began in the mid-1950s in Sugar Grove, West Virginia, but was abandoned after the era of satellites, also known as artificial moons, began. The left image shows the most advanced stage of construction. (NRL photos 60741(36).jpg and 60834(H-174).jpg)

Lorenzen also called on a new hire, Bruce Wald, who had been working on HF/DF, that is, high frequency direction finding technology (known more colloquially as "huff-duff"), including leading-edge data-processing software, to flesh out the overall operations of the satellite. The NRL team told the Navy's Bureau of Aeronautics, which would be paying for the satellite, that the estimated price tag was \$487,900.⁸ Lorenzen served as the point man making sure all appropriate individuals and entities within the Navy and national ELINT programs and infrastructures were kept abreast of NRL's spaceward ambitions and he shepherded the approval processes through their necessary steps.

Even as NRL was gearing up to place a first-of-its-kind intelligence-gathering tool into space, the lab was asked by the newly formed Advanced Projects Research Agency (ARPA) to build a system, designated “weapons system 434,” which “could actively detect and track all space objects deployed by the U.S. or other nations.”⁹ The Department of Defense established ARPA in February 1958, just four months after the launch of Sputnik 1, with the mission, in the words of one history of the organization, “to assure that the United States maintained a lead in applying state-of-the-art technology for military capabilities and to prevent technological surprise from her adversaries.”¹⁰ ARPA considered NRL a go-to place because of the lab’s experience with the Minitrack system for tracking Vanguard satellites and its success in tracking Sputnik 1 with the Wullenweber array in Hybla Valley, Virginia. The request entailed that NRL build an active radar-emitting counterpart to be used in conjunction with each of the original passive Minitrack detection antenna sites built on U.S. territory. So in addition to the original ability to passively receive radio signals sent out by transmitters aboard spacecraft, the upgraded system would also include ground-based transmitters that could actively beam probing radar signals upward, which would reflect off of non-emitting objects in space back down to the system’s receiving antennas. The result would be an electronic detection fence in space, stretching from coast to coast over the southern states, that could detect overhead spacecraft whether they were transmitting or not.

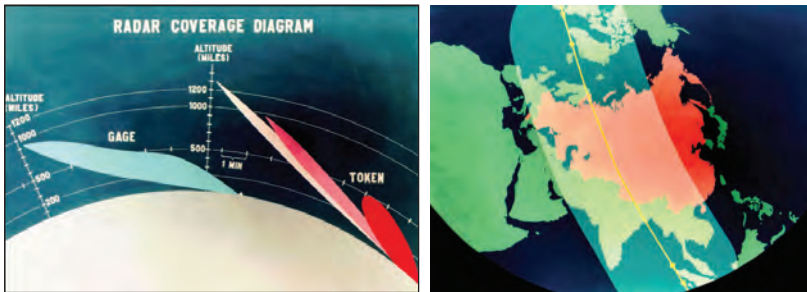
The proposal by NRL to fly a spy satellite over the Soviet Union was high stakes by every measure—technologically, institutionally for NRL, and militarily and politically for the United States. The plan could only move forward with approvals all the way up the chain to President Eisenhower. The Office of Naval Intelligence would champion the proposal within the Navy, the Department of Defense as a whole, and national intelligence leadership. NRL too would send out emissaries in search of approval.

“The first Pentagon meeting of a working group to consider the proposal of the NRL for an electronic intelligence satellite, occurred on 28 July 1958,” according to Potts, who later became an ELINT insider on the project and who eventually chronicled the secret programs for the National Reconnaissance Office.¹¹ At the meeting was an NRL contingent, representatives from the Office of Naval Intelligence, the Office of Naval Research, the Naval Security Group (NSG, which oversaw Navy ELINT issues), and the Bureau of Aeronautics. The original name of the proposed satellite could not have been more straightforward—NRL Electronic Intelligence Satellite.¹² Following a recommendation by NSG commander Frederick W. Hitz, Jr.,¹³ however, the name “Tattletale” was initially assigned as the project’s moniker.

The Pentagon meeting included briefings about what was known regarding Soviet air defense systems and an extended discussion about a much larger Air Force space reconnaissance project (conceived of for the Air Force by the RAND Corporation), designated WS-117L. To the chagrin of its planners, newspaper and magazine outlets

had also already caught wind of that Air Force project and had dubbed it the “spy in the sky satellite.”¹⁴ A representative with the Office of Naval Research (ONR) at the meeting noted that the WS-117L program was funded through 1959 with a whopping \$233.7 million, compared to the initial \$100,000 that ONR hoped to make available for NRL’s Tattletale proposal.¹⁵ As the WS-117L program shifted from paper stages to development stages, it included both photoreconnaissance and electronic intelligence payloads. But in early 1958, the two would split into programs that became known as Corona and Samos, respectively, though some satellites would carry both photoreconnaissance and ELINT payloads.

Trexler did the talking for NRL at the meeting. After all, he succeeded in winning approval for his audacious Big Ear program earlier in the decade. He used five colorful and oversized poster board charts that were awkwardly carried around in a large, locked canvas pouch from NRL to the Pentagon meeting room and subsequently many times for other briefings. One of the charts depicted the beam geometries from the Soviets’ Gage and Token radar installations as they would appear above the Earth at different potential altitudes for a satellite. Another showed how a satellite in an orbit inclined at 70 degrees that took it over Moscow, would be capable of intercepting radar signals emanating from sites 1,750 miles to the east and west of the trajectory. The resulting swath covered most of the Soviet Union’s territory, which was colored red on the chart.¹⁶



Big Charts. When NRL representatives were making their case for the world’s first spy satellite, they carried around large poster boards with colorful graphics like these to the Pentagon and other government offices. (NRL photos GRAB 3.jpg and GRAB 6.jpg)

A second meeting at the Pentagon, held on August 6, 1958, brought in representatives from additional organizations: The National Technical Processing Center (the national-level guidance and policy body for the ELINT programs) and the office of the Assistant Chief of Naval Operations for Research and Development. The meeting centered on a pros-and-cons discussion regarding NRL’s proposal and another ELINT system that several contractors¹⁷ had been tasked with building for the Air Force WS-117L-associated Sentry satellite program, whose mission was mostly in the arena of photoreconnaissance.

Momentum was building toward a leading role for NRL in placing the world's first spy satellite into orbit, but it was not yet a done deal. The situation was akin to when the Stewart Committee was considering competing proposals for a United States scientific satellite to be orbited during the International Geophysical Year. To continue strengthening NRL's position, Lorenzen brought Jack Mengel, head of the Minitrack component of Project Vanguard, and John Hagen, Vanguard's overall director, in on the top-secret loop of Tattletale.

At a third Pentagon meeting of the ELINT working group, on August 21, Lorenzen ran into a problem. Some members expressed skepticism regarding the claim by Lorenzen, Mayo, and their NRL colleagues that they could deliver what they were promising on such a minuscule budget on the order of hundreds of thousands of dollars, especially in light of the Air Force's multimillion dollar WS-117L program. In response, Lorenzen deployed his well-exercised powers of persuasion and convinced the working group to endorse the NRL proposal, despite its unlikely combination of high ambition and low cost.

Meanwhile, the Naval Security Group furthered the cause by identifying three overseas ELINT stations suitable for receiving relays when they were within "earshot" of the Tattletale satellite. And NRL brought to the table a detailed concept for "portable equipment shelters," about the size of a walk-in closet, for additional receiving and satellite communications abilities. Among the technicians behind the design and acquisition of these shelters, or "huts" as they became known, was Ed Becke, an antenna and radio frequency expert who joined the lab in 1945 and would still be working there part time even 65 years later.¹⁸ The huts could be readily moved to accommodate, among other things, unexpected orbital inclinations due to flaws in a launch (which everyone knew were likely) and changes that top-level intelligence officials might call for regarding targets for ELINT collection.¹⁹

The pieces were coming together. The Office of Naval Intelligence, located on Massachusetts Avenue on the grounds of the U.S. Naval Observatory, agreed to work with NRL on analysis of the signals from Tattletale satellites. The Bureau of Aeronautics agreed to provide the funds for five satellites and the costs associated with huts and ground stations. Providing funding for the launch vehicle fell onto ARPA's shoulders.

All this technical momentum was unfolding in a larger context as the nation was constructing and reconstructing its intelligence infrastructure. Most relevant to Tattletale were provisions of an intelligence directive on September 15, 1958, which assigned "operational and technical control of national ELINT intercept and processing activities" to the National Security Agency, specifically in its cryptography and communications intelligence (COMINT) arm. That same day, another directive established the U.S. Intelligence Board (USIB) to be run by Allen W. Dulles, Director of Central Intelligence. It would become the USIB's charge to guide and oversee overseas intelligence operations and, as such, it would have a close hand in Tattletale.²⁰

At yet another Pentagon meeting of the ELINT working group, on October 3, 1958, participants agreed it was time to move forward in the approval chain within the Navy and the Department of Defense. The chain would go all the way to the top; the participants discussed how the extreme political sensitivity of secret reconnaissance over the country's Cold War adversary would require the White House to approve each launch.²¹ After a half-dozen more meetings and seemingly endless discussion and deliberation, working group chairman Earle Hutchison, who had been appointed to be the Navy's ELINT coordinator,²² submitted NRL's final version of the world's first ELINT satellite along with the group's endorsement to Rear Admiral Lawrence Frost, Director of Naval Intelligence (DNI). On short order, Frost directed that a formal proposal be prepared for a dry run in front of CNO personnel and for the Navy's top man, Admiral Arleigh Burke, Chief of Naval Operations.²³

So eager was Lorenzen to move forward that the positive signal from Frost was enough for him and his primary deputies for Tattletale, Trexler and Mayo, to move forward as if the lab had received the green light. For Lorenzen, this included securing buy-in from five other NRL research branches for development and testing of specific elements of the system. This was a tricky business, though, because everyone else coming on board—most of whom were in the lab's Vanguard division, which had yet to be physically transferred to NASA's new campus in Greenbelt, Maryland—had to be kept in the dark regarding any details about the classified payload. Due to his experience in managing complex projects, Mayo's direct boss in countermeasures, Raymond Owens (who answered to Lorenzen), was charged with managing the expanded NRL input, the funding for the work, and the quarterly reports to the Bureau of Aeronautics. He set up a tight schedule calling for the availability of a prototype payload for testing by January 1, 1959, and an operational unit by April 1.

The team got very busy. Mayo and his assistant Vince Rose—who lacked college training, yet, like Becke, had a knack for finding solutions to just about any electronics or RF challenge—refined calculations about what the payload would have to be able to do to detect Soviet radar from space. By early November, Mayo and Rose had prepared a 16-page document with the design and specifications for this mouthful: “omnidirectional, microwave transistorized crystal-video radio receiving system suitable for mounting in a 20 [inch] metallic sphere.”²⁴ That was engineering speak for what would become the data-gathering guts of the world's first spy satellite.

Work for the shell, electronics, receivers, transmitters, and downlink antennas was assigned to appropriate NRL branches and to people with the requisite skill sets. To move forward on the testing of ground equipment, that is, the part of the system that would either send command and control signals to the metallic sphere in orbit or receive data from it, the team secured two olive-drab electronic equipment vans from the Army Signal Corps. Mayo was in charge of all of this. “Charles W. Price, a staff engineer at NRL Countermeasures Branch, did the mechanical design for the antenna and steering mechanism for the antenna,” Mayo later recalled in an unclassified inter-

view. “He used a Chrysler emergency brake as a device to clamp the mast, and parked it so the wind would not turn it. He used a Mack truck steering wheel, which only cost \$12.”²⁵

All of this unfolded *before* Admiral Burke had approved the project. It was pure chutzpah on the part of Lorenzen, a sign of how confident he felt about telling the highest echelon of the nation’s military decision makers the way it was going to be. In preparation for the all-important briefing for the CNO, Mayo oversaw the production of a series of poster boards with artists’ conceptions of Tattletale’s newly designed signal-collection architecture and components, including a pastoral view of a radio receiving hut, its door open to reveal its electronic equipment. Next came the on-site rehearsals, or “murder boards,” in front of all of Lorenzen’s bosses at the lab: Radio Division superintendent Dr. Louis Gebhard, his deputy, Dr. Allen H. Schooley, their boss, NRL Director of Research Dr. Robert M. Page, and the lab’s Commanding Officer, Captain Peter Horn.²⁶

The NRL team had not yet reached the end of the gauntlet. In yet another important pre-CNO briefing at the Pentagon on November 25, 1958, Lorenzen’s satellite champions managed to secure essential approval for Tattletale from several dozen decision makers throughout the Navy’s command structure. In a particularly harrowing moment, DNI Frost, who had some expertise in communications, inquired about the specific frequency that would be used for command and control with the satellite. Lorenzen, always cognizant of the need for maximum security, replied—beginning with a respectful “Sir”—that the DNI did not need to know this operational detail. There was a pause. Then Frost wholly concurred, reminding the group that this compartmentalization of information was an important security measure for a project such as the one they were in the process of furthering.²⁷

The next pitch was to the Navy bureau chiefs, the Chief of Naval Materiel, and their respective staffs on December 1. Just two days earlier, Convair, an aircraft manufacturer that had diversified into the rocket business, demonstrated a successful full-range launch of an Atlas ICBM. Confidence in the U.S. entry to space was ascendant, but so was a sense of competition with the Soviet Union.²⁸

The stage was set for Lorenzen to do a make-or-break briefing on December 8, 1958, directly to the CNO Admiral Burke and his senior staff at OPNAV (Office of the Chief of Naval Operations). Afterward, when the Admiral volunteered to sign any necessary papers for getting ARPA to move forward with the launch vehicle, the briefing team knew it had successfully navigated through the approval labyrinth, at least as far as the Navy and the Defense Departments were concerned.

As all of the managerial, procedural, and authority-seeking work was going on in conference rooms at the Pentagon and elsewhere, RF engineer Marty Votaw was moving the hardware side of Tattletale forward at a speed that exceeded Lorenzen’s expectations. By December 12, he was able to report that the only component not yet ready for integration was the payload’s receiver.

Given the melding of military and intelligence requirements in this unprecedented space-based ELINT project, Lorenzen and NRL, and even Admiral Burke and his Navy Department in which NRL resided, still needed the intelligence community to flash a green light on Tattletale.²⁹ This time, the briefing team, including Trexler from NRL and Hutchison of the Office of Naval Intelligence, took its show on December 18 to Central Intelligence Agency headquarters in Langley, Virginia. There, they briefed 17 people with representation from intelligence bodies associated with all of the military services, CIA, National Security Agency (NSA), the State Department, and elsewhere. Among the CIA representatives was Herbert P. Scoville, who was a principal player in the WS-117L program, the Air Force reconnaissance satellite whose planning and development was running in parallel with that of Tattletale.

By now, word of Tattletale's potential payoffs was circulating in the U.S. Intelligence Board. Additional high-level briefings focused on the satellite's ability to detect, characterize, and localize two of the Soviet Union's primary air defense radar systems (Gage and Token). As such, the ELINT satellite held promise to greatly further the overall strategic goal of getting long-range, nuclear-armed bombers to targets deep inside the Soviet Union before they could be shot down.

No matter how many in the military or intelligence communities approved of Tattletale, it still would only make it into orbit if ARPA—the organization that would be in charge of the satellite's rocketed ferry ride into orbit—officially shifted its priorities toward supporting the ELINT payload's launch. On January 19, 1959, Lorenzen put on his briefing hat yet again, and with representatives from the Assistant Chief of Naval Operations for R&D, made a pitch to a contingent of top-level ARPA officials and civilian employees. Among them, conveniently, was James Spriggs, who had worked on countermeasures at NRL with Lorenzen during World War II and had now been assigned as ARPA's primary point of contact with the lab. At this meeting, ARPA's deputy director, Rear Admiral John Clark, recommended that the way to expedite the project toward deployment was to get the Joint Chiefs of Staff (JCS) to formally endorse it and send to ARPA a letter specifying the project's urgency.³⁰ This was a procedural step that would enable ARPA to make NRL's ELINT satellite a priority project. The Secretary of the Navy also urged Hutchison, the Navy's highest level ELINT official, to seek out negotiations with the JCS.

On January 29, the advocates of Tattletale took up the advice. Trexler briefed JCS's intelligence staff on the project's technical aspects. Hutchison fielded questions regarding the relationship between the new satellite-based means of ELINT that NRL was proposing and the National Technical Processing Center, which oversaw national ELINT programs and procedures. The vibe was good, so much so that Trexler left with suggestions from JCS attendees of future ELINT targets to pursue, a tacit hint that a new long-term relationship with JCS was beginning.³¹

All the while, Votaw and his team at NRL were bending metal—the fabrication of a 20-inch aluminum sphere in the image of the Vanguard satellites was in the works—

and designing and soldering miniaturized circuits. For the mission's data transmitter, engineers at the Army Signal Corps Laboratory in Fort Monmouth, New Jersey, were developing a 24-volt power supply with solar cells and rechargeable nickel-cadmium batteries. Edgar Dix, second in command to Votaw, was applying his experience in developing the Vanguard transmitter to both the space- and ground-based transmitters for the Tattletale communications system. For his part, Mayo had moved the payload antennas from design and prototype phases to a contract phase with International Telephone and Telegraph (ITT), which was tasked with producing the antennas. He also was assessing the state-of-the-art recording equipment that could be suitable for the mission while overseeing Charlie Price and his engineering team as they designed the communications huts from which the satellite handlers would conduct command and control procedures and collect data from the satellite's recorders.³²

All of this was proceeding still without having an official green light in hand. Mayo and Lorenzen were doing all they could to secure that approval. For example, upon returning by train to Washington, DC, from Fort Wayne, Indiana, where they inspected ITT's payload receiver, they were met at Union Station by NRL colleagues carrying the classified briefing boards about Tattletale. The group then drove a few blocks to the House Committee on Science and Astronautics, which at that very time was reviewing Navy space projects. NRL's Tattletale was not the only satellite proposal on the Committee's agenda, nor was it even the one considered most important. That distinction went to the Transit satellite, designed for the Navy by Johns Hopkins University's Applied Physics Laboratory (APL). Its role? To provide navigational guidance to nuclear-missile-carrying submarines at sea.³³

Cordial as the Committee meeting was, there now was a potential conundrum. The Navy had two satellites to launch, but ARPA was only in a position to orchestrate a single launch in the near future. These were trailblazing times in the Space Age, so this dilemma instigated some creative thinking. At their Pentagon office on March 12, 1959, ARPA representatives met with Lorenzen of NRL and ONI's Hutchison and boldly suggested that the smaller, lower-profile Tattletale payload and the larger, top-priority Transit payload be launched at the same time with one rocket. A first-ever two-satellite launch! This scenario entailed risks that single-satellite launches would not, and these already were highly risky. Even so, subsequent discussions culminated in a meeting at APL in Howard County, Maryland. There, Transit engineers Richard Kershner and Theodore Wyatt agreed that a Tattletale co-launch with Transit would work and was worth the risk. It looked like Lorenzen and his Tattletale colleagues finally had secured a ride into space for their first-in-the-world ELINT mission.

On a particularly busy March 16, Lorenzen and other Tattletale champions conferred with former Vanguard team members, who by then were at NASA headquarters, to secure the new space agency's supportive role in providing tracking data with the Minitrack system that transferred to NASA with Project Vanguard. Later in

the same day, Lorenzen, Hutchison, and NRL's Bruce Wald traveled to the Pentagon to meet with ARPA and APL representatives to work out organizational and administrative details of the Tattletale/Transit dual launch. Although both satellites had the ARPA-funded launch in common, each had different sponsors, command, and oversight mechanisms.³⁴ These administrative and sociological factors were every bit as complicated as the engineering and technology development aspects of the mission, and probably were the ones more likely to scuttle the project.

As the pieces were falling into place for an actual launch of a Tattletale satellite, the national infrastructure for handling the payload's anticipated highly classified data was in the process of getting hammered out. Essentially, all of the ELINT roles of the National Technical Processing Center were to transfer to the National Security Agency. To hedge against delays in data analysis amidst this reorganization, NRL and NSA partners set up a stopgap operation to handle data issues in the near term.

There never seemed to be a shortage of obstacles, including one posed by the Navy itself. The first Transit launch had been scheduled in 1959 and the CNO's office had officially requested that the Bureau of Ordnance (which was funding the Transit program) include Tattletale in a piggyback launch. But the Navy's Bureau of Ordnance turned down the request, fearing that there was a good chance the second satellite's inclusion would cause a delay in the launch of Transit, which was an all-important navigational component of the submarine-based Polaris missile system. Had that launch opportunity for Tattletale been approved, the world's first spy satellite might have made it into orbit before 1960. Instead, the plan was for the first Tattletale satellite to ride piggyback on the launch of the second Transit satellite.³⁵ The delay turned into good fortune. As it turned out, the launch of Transit 1A on September 17, 1959, failed due to a malfunction in the rocket's third stage.³⁶

The risk of getting scuttled seemed always present for another reason: ARPA controlled the rockets—the means of getting any military satellite into orbit—and the organization was under pressure from many directions. For one thing, there still was concern at ARPA that Tattletale could foist delays not only on the Navy's Transit payloads but also on the Air Force's WS-117L-derived Samos program. Among the concerns was that any revelation of the ELINT capabilities of Tattletale could alert the Soviet Union to U.S. capabilities before subsequent and more sophisticated satellite-borne ELINT sensors would have an opportunity to snoop with a fully intact covert status. "The possibility of completely covert detection would be lost, and the Russians might take steps to thwart or confuse it," wrote Potts.³⁷

A moment of intense angst about security entered the picture at this point. For an intelligence project of this novelty and sensitivity, a lot of people—perhaps too many—had been brought into the loop. And the risks of that became painfully evident by way of an alleged leak: a story on the program that even revealed the code name Tattletale appeared in the *New York Times*, according to several official but short accounts of the program.³⁸ Because of the alleged leak, the program now was

vulnerable to cancellation. In a quest to salvage the program and to do so in a way that would tighten its security, leaders in the growing national intelligence program hatched a plan in which the ARPA director would send a memorandum to the Under Secretary of the Navy that would “disapprove” Tattletale. That same step also would open a way to solving a concern about the program’s title, which to some had been too suggestive of its actual mission. The program would continue under the far more tightly held security control system, dubbed Canes (the security system and the payloads subsumed by it were often referred to by the same word). This time, only those who needed to know about it would be brought into the project.³⁹

This move would require yet another round of briefings and approvals in top-level intelligence circles. On June 3, CIA leadership, including Richard Bissell who was in charge of the agency’s aerial and satellite reconnaissance program, agreed that what was needed was a letter from Roy Johnson, ARPA’s founding director, to the Director of Central Intelligence (DCI), Allan Dulles. In the letter, Johnson would spell out Canes (and the program formerly known as Tattletale) and the implications it might have for the programs under Bissell’s watch, among them, the high-flying U-2 and supersonic Blackbird photoreconnaissance spy planes.

On June 8, ARPA envoys delivered that letter to Dulles. The package included a cover letter from the office of the Secretary of Defense urging the DCI’s approval of NRL’s ELINT satellite proposal as it would significantly reveal and characterize Soviet air and missile defenses and other electronic and signals-based technological capabilities. The following day, during a meeting of the United States Intelligence Board, Dulles gave the go-ahead.⁴⁰

Tattletale qua Canes—the project upon which NRL’s own future in the Space Age would at least partially depend—faced yet additional obstacles. In particular, those pushing for the Air Force reconnaissance program, Samos, were still worried that the NRL project could sap the same ARPA resources that Samos needed to make it into space. Luckily for NRL, ARPA director Johnson had been won over by the lab’s proposal. He recommended to the new Deputy Secretary of Defense, Thomas Gates, that he send a letter (which Johnson provided) to President Eisenhower requesting a green light for Canes. The letter argued that Samos and Canes were complementary, that Canes would be able to evaluate the ELINT performance of Samos’s electronics package, and that the simplicity of Canes hedged the possibility that the complexity of Samos would introduce delays and therefore intelligence gaps. Johnson was playing on the sense of Cold War urgency by the President for data on the Soviet Union’s anti-aircraft and anti-ballistic missile radar programs. Also in the letter, Johnson suggested a name for the scientific cover mission for Canes that NRL would need to execute in order to keep Canes secret: Galactic Radiation Experiment Background, or GREB.⁴¹ This would not be the cover name that finally would stick.

The nuanced language in the letter regarding how the top-secret ELINT proposal was cast in the larger context of military and national intelligence-gathering efforts

reveals political realities. The NRL proposal became, in the letter, “an interim electronic intelligence capability which can be accommodated within the Department of Defense’s navigation satellite development program,” referring to the Transit satellites, whose role was to improve the targeting and survivability of the submarine-based Polaris nuclear missiles.⁴²

On July 13, 1959, Deputy Secretary of Defense Gates signed a letter approving the “technical development and planning” of Canes—which Lorenzen, Mayo, and their engineers and technicians had been doing all along anyway—and had it delivered to President Eisenhower. The same day, the Chief of Naval Operations, Admiral Burke, circulated a classified memorandum defining Navy space policy, titled “The Navy in the Space Age,” which was based in part on a study orchestrated by Captain Thomas Connolly of the Navy’s Bureau of Aeronautics.⁴³

“Highest priority within the astronautics program will be given to immediate development of space vehicle systems to improve fleet capabilities in the fields of reconnaissance, communications, navigation, sea launching and recovery of satellites, and meteorology,” the policy memorandum stated. “These will exploit the potentialities of U.S. command of the sea and will determine parameters of enemy capabilities.” Highlighted later in the statement was an “ECM satellite program,” referring to Canes.⁴⁴

At the same time, the letter from Gates, the Deputy Secretary of Defense, to President Eisenhower hit resistance. One issue was anchored in the valuation by many of the photoreconnaissance promised by the Samos program as higher than ELINT data. But the major sticking point for the White House’s technical brain trust, helmed by Brigadier General Andrew Goodpaster and George B. Kistiakowsky, the President’s science adviser, was risk of detection by the Soviet Union.⁴⁵

As such, NRL took up the task of fully analyzing the risk. For that, Lorenzen turned to Wald, who was deft in the mathematics of electromagnetism and radio frequency technology. He also had expertise in statistics and proved to be a pioneer at the lab in the use of electronic computers. His analysis revealed that the Soviet Union indeed could detect a Canes satellite, but that the probability of doing so if it was unaware of the program’s existence was 0.03 percent, or only about 3 in ten thousand. And even if the United States’ Cold War adversary were suspicious that it was subject to a covert ELINT program and so made a maximum effort to find U.S. ELINT satellites, the probability of discovery, Wald calculated, would increase only to 1 in a thousand. Key to the calculations was a combination of the ability to turn the satellites’ RF emitters on and off and the finite lifetime of the satellites. In short, the Soviet Union would not have the luxury of time to find what it was looking for.⁴⁶

In the end, the letter that Secretary of Defense Neil McElroy sent to the President on August 18, 1959, amounted to a strong recommendation to move forward with “the Canes project,”⁴⁷ here again using the code word for the overall security framework for the project. The letter reiterated the value of Canes for capturing and



Out of the Box. One of the more colorful characters in the history of NRL, Dr. Bruce Wald (shown here in 1974), an early adopter of both the soft and hard components of digital technologies, played critical roles in developing the overall ELINT and other systems built by the lab's space technology teams. (NRL photo Wald(2).jpg)

relaying signals from “Soviet radars and other electronic equipment operating anywhere in the USSR,” as opposed to only near the borders where such signals already were monitored using land- and air-based intercept equipment. The letter also conveyed strong Air Force opposition based on the argument that Canes was essentially duplicative with respect to the ELINT capabilities of Samos. Wald’s analysis of the risk of detection bolstered the letter’s recommendation to go forward with Canes. The letter acknowledged also that the intelligence payoff expected from Canes was not big enough to justify its own launch, but that the planned launch of the next Transit satellite and the relative cheapness of Canes if launched with the Transit payload, rendered the NRL ELINT program a good one to move on. In the letter to the President, Secretary of Defense McElroy included the recommendation from the Secretary of State that “the project be approved with the proviso that periods during which the device obtains and transmits data be subject to the approval of the President on the recommendation of the Secretary of State.”⁴⁸

Weighing in with a modest concurrence at best was science advisor Kistiakowsky who told the President’s confidant, Brigadier General Goodpaster, that the Canes project could provide some useful information, but that it was not a must-do project. “My present position is a recommendation to approve, but not a strong one,” Kistiakowsky wrote in a memorandum dated August 20, 1959. “I do not think that a failure to approve will hurt our interests seriously.”⁴⁹ Whether NRL’s spy satellite would go into orbit now hung on a decision by the President of the United States.

Four days later, with critical assurances by Mayo and Lorenzen that the NRL team would conduct a testing phase beyond the range of Soviet detection and they would build in an ability to “turn off the payload at a moment’s notice,” President Eisenhower approved project Canes.⁵⁰ And with his signature, he would help set the future course of NRL’s role in the U.S. space program.

In the approval memo, the President included language that would lead to the establishment of the National Reconnaissance Office (NRO) in 1961, an agency whose very existence would remain classified until 1992. “This approval highlights the need for a control organization within the Defense Department to provide effective and

unified operational control and coordination of these and other satellite devices designed to serve operational purposes,” the President wrote to the Secretary of Defense. “I understand that you are studying this matter and I look forward to considering with you a plan for such an organization.”⁵¹

Two days after that, on August 26, the Chief of Naval Operations, Admiral Burke, told his senior admirals that satellites, in the coming years, were going to be important for naval operations. He recommended that each fleet commander should begin setting up small space sections with personnel who would remain cognizant of emerging space-based capabilities and how these would influence war planning, readiness, and other military basics.⁵²

Now, finally, with the full-fledged approval in hand, and authority based in the President’s office, the remaining technical steps had to be taken, money had to be officially allocated, and final official orders—including from the Bureau of Ordnance, which was the sponsor of the Transit satellite on which Canes/GREB would ride piggyback as an ancillary payload—had to be registered. Specific tasks, such as the design of an interface for the two satellites, also had to be assigned to engineers at APL and NRL. Of utmost importance was the Canes security control protocol; only 50 individuals in the military and intelligence communities were initially signed into it and cleared for participation in it. Now, finally, the challenge was largely in the hands of NRL’s engineers who were eager to get the world’s first reconnaissance satellite into orbit.

¹ Ronald L. Potts, *U.S. Navy/NRO Program C Electronic Intelligence Satellites (1957–1977)*, LEO Systems Program Office, National Reconnaissance Office, September 3, 1998, declassified with redactions and approved for release from NRO on June 13, 2012, p. 9; see also Robert A. McDonald and Sharon K. Morena, *Raising the Periscope... Grab and Poppy: America’s Early ELINT Satellites* (Chantilly, VA: Center for the Study of National Reconnaissance, National Reconnaissance Office, September 2005).

² Bruce Wald, interview with author, May 23, 2012; script for NRL-produced video, “GRAB—NRL’s Secret Success in Space.”

³ Reid Mayo, in *Beyond Expectations—Building an American National Reconnaissance Capability: Recollections of the Pioneers and Founders of National Reconnaissance* (Bethesda, MD: National Reconnaissance Office and the American Society for Photogrammetry and Remote Sensing, 2002).

⁴ Potts, *U.S. Navy/NRO Program C*, p. 9.

⁵ Patrick W. Binning and Jay W. Middour, “A Brief History of NRL’s Early Firsts in Spaceflight,” *Advances in Astronautical Sciences* 129 (2008): 1233–1250.

⁶ Potts, *U.S. Navy/NRO Program C*, p. 9.

⁷ David K. van Keuren, “Cold War Science in Black and White: US Intelligence Gathering and Its Scientific Cover at the Naval Research Laboratory, 1948–62,” *Social Studies of Science*, vol. 31, no. 2, Science in the Cold War (April 2001), pp. 207–229.

⁸ Potts, *U.S. Navy/NRO Program C*, p. 10.

⁹ Potts, p. 10.

¹⁰ Richard van Atta, “Fifty Years of Innovation and Discovery,” in *DARPA: 50 Years of Bridging the Gap* (Washington, DC: Defense Advanced Research Projects Agency, 2008), p. 21.

- ¹¹ Potts, *U.S. Navy/NRO Program C*, p. 12.
- ¹² Mayo, in *Beyond Expectations*, p. 134; see also <http://www.fas.org/spp/military/program/sigint/grab.htm>.
- ¹³ Frederick Hitz would attain the rank of captain; Potts, *U.S. Navy/NRO Program C*, p. 158.
- ¹⁴ Potts, *U.S. Navy/NRO Program C*, p. 12.
- ¹⁵ Potts, p. 12.
- ¹⁶ *Labstracts*, Naval Research Laboratory, Washington, DC, June 22, 1998; “GRAB: Galactic Radiation and Background: First Reconnaissance Satellite,” pamphlet prepared by NRL (revised edition, April 2000).
- ¹⁷ Airborne Instruments Laboratory, in Mineola, NY, and Haller, Raymond, and Brown in State College, PA.
- ¹⁸ Edward Becke obituary, *Capital Gazette*, October 15, 2013, accessed online, <http://www.legacy.com/obituaries/CapitalGazette/obituary.aspx?pid=167547742>.
- ¹⁹ Potts, *U.S. Navy/NRO Program C*, p. 14.
- ²⁰ Potts, p. 14.
- ²¹ Potts, p. 15.
- ²² Potts, p. 11.
- ²³ Potts, p. 11.
- ²⁴ Potts, p. 16.
- ²⁵ McDonald and Morena, *Raising the Periscope*, p. 35.
- ²⁶ Potts, *U.S. Navy/NRO Program C*, p. 16.
- ²⁷ Potts, p. 16.
- ²⁸ Potts, p. 16.
- ²⁹ Potts, p. 18–22.
- ³⁰ Potts, p. 20.
- ³¹ Potts, p. 20.
- ³² Potts, p. 21.
- ³³ Potts, p. 22.
- ³⁴ Potts, p. 23–24.
- ³⁵ Potts, p. 25.
- ³⁶ Tina Thomson (ed.), *Space Log, 1957–1987* (Redondo Beach, CA: TRW, 1988).
- ³⁷ Potts, *U.S. Navy/NRO Program C*, p. 26.
- ³⁸ The leak to the *New York Times* is mentioned, but not referenced, on page 2 of “A History of the Poppy Satellite System,” prepared for the National Reconnaissance Office by Ronald L. Potts. NRO released the document, with many redactions. The same leak also is mentioned, again without a specific reference, on page 31 of *From the Sea to the Stars: A Chronicle of the U.S. Navy’s Space and Space-related Activities, 1944–2009* (revised and updated edition, 2010), which was prepared by the Applied Research Laboratory of The Pennsylvania State University (editing body), and sponsored by Deputy Assistant Secretary of the Navy (C3I and Space) Dr. Gary A. Federici. A search in the *New York Times* archive did not yield the alleged article.
- ³⁹ Potts, *U.S. Navy/NRO Program C*, p. 27.
- ⁴⁰ Potts, p. 27.
- ⁴¹ Potts, p. 30.
- ⁴² Potts, p. 30.
- ⁴³ Potts, p. 31.
- ⁴⁴ Potts, p. 30.
- ⁴⁵ Potts, pp. 31–32.
- ⁴⁶ Potts, pp. 31–32.
- ⁴⁷ Potts, pp. 31–32.
- ⁴⁸ Potts, pp. 31–32.
- ⁴⁹ Potts, pp. 31–32.
- ⁵⁰ Potts, p. 34.

⁵¹ Potts, p. 34.

⁵² Potts, p. 34.

9

RAISING THE PERISCOPE: GRAB 1 AND 2

To further its mission to realize the now Presidentially approved ELINT project, NRL worked in late August 1959 with the Naval Security Group to prepare a top-secret description of “a U.S. electronic satellite experiment.” They referred to the payload with a nonrevealing, innocuous name, GRAB, for Galactic Radiation and Background or, as some sources have it, Galactic Radiation Background experiment (though the acronym still seems to convey a sense of interception!), which, unlike the code name Canes, could be used in unclassified correspondence.¹

A challenge now for Howard Lorenzen and his spy satellite team at the lab was to create a firewall between GRAB, the ELINT payload of the satellite, and the scientific payload that would share the same satellite housing and which would later become publicly known as SOLRAD, for Solar Radiation. So stringent was the security Lorenzen wanted to maintain, that his countermeasures group in the Radio Division (the Canes/GRAB team) had to work entirely separately from Marty Votaw’s Satellites Techniques Branch in the Applications Research Division, whose scientists and engineers were building the SOLRAD payload. The challenge in keeping this firewall intact was that both payloads had to be integrated into the same single spherical satellite shell.

No one working on the SOLRAD mission, except perhaps for Herbert Friedman, knew the full story. The countermeasures team working on the GRAB payload did so at night when the Satellite Techniques Branch working on the SOLRAD payload already had gone home.² And the two groups were never mentioned together in any distribution list, even of unclassified materials.

The pieces were coming together, literally. Contractors delivered crystal video receiver and antenna components to Vince Rose in September 1959, for example, and then Rose moved them, under the cover of night, to Building 59 where NRL’s pioneering satellite builders were doing their parts in testing and integrating the spacecraft’s subsystems. Meanwhile, the detailed plans for collecting and distributing GRAB’s expected intelligence harvest over the Soviet Union were getting laid down. For example, under the direction of NRL’s Charlie Price, reception huts would be prepared and installed at existing ELINT stations where technicians would be trained to operate and maintain them.

“The output of the payload,” NRL’s Bruce Wald recalled in a memoir, would be “sent to receiving huts placed around the periphery of the Soviet Union and recorded



The Huts. An important part of the world's first ELINT spy satellite system were portable command, control, and listening huts placed around the periphery of the Soviet Union and elsewhere by which operators could communicate with GRAB satellites as they passed overhead. Included in this photo are Countermeasures Branch Head Howard Lorenzen (leftmost on bottom), GRAB Project Engineer Reid Mayo (leftmost at top), hut operators in the sailor hats, two officers, and Radio Control Hut Engineer William Edgar Withrow (rightmost at bottom). (*NRL photo Radio.tif*)

on two-track 1/4-inch magnetic tape such as was used to record music.” One track would record the receiver output and the other a time code, he noted.³

The plan called for the Armed Forces Courier Service to forward data tapes from these huts to NRL in Washington, DC, where the data would be checked, copied, and couriered to the Naval Security Station on Nebraska Avenue, NW, just a few miles away. There, under the auspices of the National Security Agency, ELINT specialists within the office of Collection and Special Analysis (COSA) would make sense of the data. These analysts were charged with eking from the data as much information as possible about an intercepted radar source's power, location, frequency, pulse pattern, and any other technical and physical traits the data could reveal. To brief the commanders of each ELINT station, and work out the logistics for the arrival and operation of the huts, Lorenzen and Mayo all but circled the world with 35-millimeter slides of the original briefing boards they used at the Pentagon and Capitol Hill when the project was still known as Tattletale.

Despite the momentum, there never were any guarantees that the project would make it through what amounted to a continuous and unending gauntlet of potential showstoppers. This was a time when any single space project would progress in parallel with a good number of others, each one with its own set of champions, sponsors, approval chains, and organizational, sociological, and cultural peculiarities. Some changes decentralized the various space projects while others seemed to centralize

them. For example, in late 1959, ARPA's ascent toward a central role began to give way to a more balkanized control of space projects in the different military services. As Secretaries of this or that federal department came or left, or as champions of this or that program changed their own personal or professional trajectory, so too would the emphases, priorities, funding, and momentum on different space projects shift. Whatever NRL and other Navy organizations imagined their roles in the U.S. space program would be, these were floating in larger tidal currents. One trend that seemed more discernible than others, as well as more worrying to the Navy's GRAB team at NRL, was that the Air Force seemed to rise above other government entities in the mix. An unmistakable sign of that resided in a shift of 85 percent of the \$487 million that had been designated to ARPA for fiscal year 1960 to the Air Force's space budget.

As a tiny and highly classified project amidst giants, and literally piggybacking on the higher-priority Transit program, Canes/GRAB was in constant need of shepherding by its most ardent champions. At this point, fewer than 200 people in the Washington, DC, area had been cleared within the Canes security program. It was a small club that helped maintain security but it also was a liability when it came to keeping the ELINT project in the forefront of decision makers' minds, especially during budgetary discussions. An unintended consequence of the public scientific cover for the ELINT payload was that it would help out in this regard.

Integrated in the same satellite shell along with the GRAB payload was the scientific package for measuring solar radiation at the top of the atmosphere and beyond.⁴ In charge of the science mission, which became known as SOLRAD, was Herbert Friedman and his space science team, which had earned accolades and publicity when they were doing pathbreaking, rocket-based upper atmosphere research, first with V-2 rockets and then with a variety of sounding rockets, most notably Aerobees and Vikings.

The first SOLRAD would kick off a long series of solar radiation and upper atmosphere science payloads that collectively would contribute enormously to space-based science—solar science in particular—and would open pathways for decades to come for NRL's Space Science Division, the roots of which were established in 1952 even before the Vanguard program had been conceived.⁵ SOLRAD 1 would serve double duty as a public cover that would enable the GRAB payload to be integrated into the unclassified Transit launch. But, as mentioned before, that meant one single spherical shell would have to accommodate two payloads. It fell onto the shoulders of Votaw, chief design engineer, and the specialists under his supervision to prepare the satellite for this dual purpose. Among those was a new hire, Peter Wilhelm, who would become one of the most consequential drivers of the country's non-civilian space program for more than a half century. Under Votaw's supervision and with Dix's technical mentoring, Wilhelm's assignment at the time was to build the satellite's transmitters. Wilhelm knew nothing about the secret payload his work would contribute to, but he knew he was pushing the technology envelope.

“This transmitter was supposed to operate at—I think it was 136 or 137 megahertz [MHz],” Wilhelm recalled. “You know, the Vanguards had operated at 108 MHz. And the thing that enables a transmitter to be stable is a crystal. And physically being able to make a crystal that [small]—the higher the frequency, the smaller the crystal gets—was really pushing it. And they were very thin. They were mechanically fragile, difficult to make. There was a little company up in Pennsylvania, McCoy Crystal, which cut these crystals and polished them. And then you have to plate the anodes on both sides, electrodes ... And so my job was to take all of the crystals that McCoy could make, that [they] even felt [were] worth shipping, and test them and see, you know, what was the frequency stability.”⁶

Wilhelm also got the assignment of testing the transistors that Bell Labs was shipping to the Satellite Techniques Branch and that presumably would enable Wilhelm to build a small, lightweight transmitter whose components would fit on a palm-sized disk, which would go inside the satellite’s shell. “They would come in ... twos and threes at a time in a little box, and I’d plug them in and test them, and a lot of them wouldn’t operate at all at 130 MHz ... And when you found a transistor that worked, boy, you treated it like gold.”⁷

“Everything was on the edge of working or not working,” Wilhelm recounted. “When you would tune these transmitters up, if you put your hand near them, sometimes they would stop oscillating altogether. I mean it was that hairy.”⁸ Wilhelm pointed out another huge challenge. “Trying to get everything we needed to get into the satellite within the weight limit—it was only a 40-pound satellite operated on 6 watts of power,” Wilhelm explained. “Everything was really marginal.”⁹

Wilhelm soon would learn from Mayo and Rose about the technical details of the classified payload that his transmitter also would serve.

The data reception and command-and-control pieces of the project, under Price’s leadership,¹⁰ were humming along at the end of 1959. Following mock-up experimentation with two electronic equipment vans on loan from the Army, Price took delivery of the Helicop-Huts. Price supervised the fitting of these huts with receiving equipment. One of the huts was fitted with a two-way system that specific operators at NRL and elsewhere could use to “interrogate” satellites (receive data and telemetry about a spacecraft’s health) and to send them commands. Another hut was set up to do both. Fully equipped, the huts weighed in at about 2,600 pounds.¹¹

About two-thirds of the way into fiscal year 1960, a budget crisis loomed and threatened all the momentum; funds for the GRAB payload were running out. The cost shortfall for the NRL space project was stunningly small, on the order of \$172,000, amidst the several-billion-dollar figure for missile programs and the roughly \$800 million for NASA. Even so, NRL’s ELINT satellite, which had been set for a summertime launch, was in jeopardy again. With an it-will-happen-come-what-may attitude that had come to characterize NRL’s GRAB effort, Price continued getting

the huts ready by preparing instruction manuals and sending two-man installation teams to the hut sites around the world. Wilhelm continued working with fickle transistors to build space-worthy satellite transmitters. The same can-do attitude was at work with groups on other satellite subsystems, among them ones for attitude control, power management, and thermal control. The whole team was heartened on April 13, 1960, by a successful launch of a Transit 1B satellite for submarine navigation, the replacement for the satellite that was lost the previous September.

Another reconnaissance program, one based on high-flying U-2 aircraft shaped like gliders and equipped with powerful cameras, added urgency to the need for ELINT collection. Photos of an April overflight of south central U.S.S.R. revealed, in the words of National Reconnaissance Office historian Ronald Potts, “evidence of huge fixed-array radars in various stages of construction on the western side of Lake Balkhash and perhaps several other locations that remain classified.”¹² At the same time, the Air Force’s Samos project was suffering delays. As such, Secretary of Defense Thomas S. Gates wrote to President Eisenhower on April 27 to inform him that NRL’s GRAB project was on track. He recommended that the ELINT payload be launched with the Transit 2A navigation satellite from the Atlantic Missile Range at Cape Canaveral, so that it could undergo an on-orbit testing phase and then be ready for operational use by June 20.

On May 1, 1960—four days after the Secretary of Defense sent the letter—one of the Cold War’s most momentous events would accelerate the situation. On that day, a U-2 aircraft on a photoreconnaissance mission was shot down over Soviet territory. Pilot Gary Powers survived the shoot-down and was taken into Soviet custody. The U.S. claimed initially that the aircraft had wandered off course as it was making meteorological measurements. With de facto proof now that the Soviets had both anti-aircraft radars capable of tracking high-flying aircraft like U-2s, and surface-to-air missiles capable of shooting them down, President Eisenhower immediately suspended flights of the spy planes. That meant a uniquely revealing intelligence window on the Soviet Union had been sidelined. On May 5, the President approved the GRAB launch, stressing that the ELINT payload was to be activated only if and when he personally gave the OK to do so.¹³

For all of its top secrecy and increasing sense of urgency all the way up to the President’s office, NRL’s engineering team on the program had a flair for moving things forward. “For safe handling and a low profile,” Potts revealed in his once-classified history, “two fully tested, 42 pound satellites, were readied for transport in a private station wagon, which its owner, Ed Dix, would drive down to Florida, accompanied by Mayo and a muscular escort.”¹⁴ Spirits were high among both teams at NRL—Lorenzen’s GRAB team, and Friedman’s SOLRAD team—as the launch date approached.

The value of redundancy showed itself immediately. One of the satellites, as it turned out, had a cracked solar cell and a couple of flawed circuits in the electronics

package of the ELINT payload. Luckily, its twin checked out fine. An engineer and technician from NRL attached the small orb to the APL-designed interface atop the larger Transit satellite. The rocket contractor in the project, Aerojet General, secured the payload fairings like eggshells over the satellites and then mated the payload to the upper stage of the Thor Able Star booster. Next came the fueling. And then, at last, the countdown for launch of the world's first spy satellite began.



Double First. An artist's drawing depicts the Applied Physics Laboratory's Transit 2A satellite and the Naval Research Laboratory's solar radiation measurement satellite shortly after their planned separation. On June 22, 1960, the two satellites were launched in a piggyback style and then the smaller NRL SOLRAD satellite was released from the Transit satellite by spring force. When this image was publicly released, the GRAB payload inside SOLRAD's shell was highly classified. (NRL photo 60414.jpg)

"This was all new to me because I had never been at a launch site before," Mayo said. "Because of the military mission and my presence in the ELINT community, I was asked to keep a pretty low profile. If any visitor showed up in the area, I would disappear. We were not involved in the countdown process at all. We were not in any pictures. In fact, a rumor existed that we might have some religious feelings about being photographed."¹⁵

At 1:54 a.m., in the dead of night, on June 22, 1960, the rocket lifted off and headed south by southeast. The second stage separated from the first stage and then fired for 7 minutes, ascending ever higher over Brazil, and then another short booster burst took the two-satellite payload into a circular orbit. There, a spring mechanism sent the payload into a slightly elliptical orbit. Even before it circled the globe once, another mechanism separated the NRL satellite—with its deeply secret mission embedded within its openly scientific one—from APL's Transit satellite. In short order, the NRL satellite deployed its antennas, and the Minitrack system, now run by NASA, began tracking it.

The Department of Defense issued a press release with accurate but incomplete news that a solar radiation experiment had been launched along with the Transit 2A satellite. Highlighted was that this was a first-of-its-kind piggyback launch of one satellite atop another. Not mentioned was the enormous space first of putting a spy satellite into orbit. This was a first the Soviet Union now would be unable to claim. But only a few hundred people with top secret clearances could know about this Cold War trophy for the United States.

Even as the satellite circled the planet, the most important question remained unanswered: would the GRAB payload work? A five-man team—Howard Lorenzen, Reid Mayo, Ed Dix, William Edgar Withrow (an antenna design expert), and Vince Rose—loaded with electronic, testing, and other necessary equipment, traveled to a still undisclosed location in Hawaii where a 6-foot by 11-foot hut customized for “interrogation and collection” had been set up. On July 4, 1960—the first Independence Day for Hawaii, which had just gained statehood—the team crammed inside the hut, and during the satellite’s 199th orbit, the team picked up the payload’s tracking signal. Then, Ed Dix tried to activate the downlink transmitter, which Pete Wilhelm had designed and built as his first project as a member of the Satellite Techniques Branch. Its job was to send intercepted data from Soviet radar installations to antennas atop receiving huts that had been placed in friendly but undisclosed locations.

“We pushed the button and nothing happened,” Mayo recounted. “But 30 to 45 seconds later it did work. We had heart failures in between! We were all huddled inside [the hut] waiting for some sound to occur. When it happened, we all let out a shout of glee that it worked! We turned it on and we could hear radars from as far away as Japan—practically the whole Pacific area for a range of 3,500 nautical miles in all directions.”¹⁶



Listening Post. The communications huts associated with the GRAB program amounted to 2,600-pound containers that could be readily transported. Inside was electronic, radio, and recording equipment, as well as an antenna shaft that was rendered steerable with truck steering wheels. (NRL photo *Hut_Inside.jpg*)

With the satellite streaking overhead at some 19,000 miles per hour, the calibration team had only minutes to get its work done before the satellite would have passed over the horizon. And, to comply with the President’s mandate, Dix could not forget

to switch off the downlink before the satellite moved beyond the hut's line of sight. It all got done, but not before the five men in that hut heard, through an audio output, a medley of signals that GRAB had received and relayed during the calibration exercise. They could discern different frequencies (by way of audible tones) and periodicities, pulse rates, beam widths, and scanning patterns. It was music of sorts, only it corresponded to the invisible morass of radio frequency energy that had reached the satellite's antennas. Over the next two nights, the team tapped into the satellite on a total of 15 more passes and recorded the signals on magnetic tape so that they could be analyzed later back at NRL. It was clear to the team in that hut in Hawaii that GRAB 1—so named because the plan included more than one GRAB satellite—was ready for its mission: to intercept emissions from S-band air- and missile-defense radar systems throughout the Soviet Union.¹⁷

This was a national asset, not just NRL's. The Technical Operations Group (part of the Naval Security Group) managed the operation of GRAB 1, which meant it proposed specific days, orbits, and times when the satellite would be turned on and collect data as it passed over the Soviet Union. When the NSG gave the green light, operators in a "triggering hut" would activate the satellite's intercept and relay systems. The U-2 incident in early May raised the political stakes of being caught, so additional precautions, such as never operating the satellite on consecutive passes, were implemented to minimize the chance of detection by the Soviets. That way, even if the Soviets detected intermittent emissions of the specific command and relay frequencies, 138.05 MHz and 138.57 MHz, respectively, the absence of these signals over the next passes would make it almost impossible to discern a connection to an orbiting emitter.

Under Mayo's supervision, NRL representatives fanned out to all the collection huts and trained technicians at each in how to track the satellite and collect data. Lorenzen, Mayo, Rose, and Withrow traveled from the calibration hut in Hawaii to "an interrogation site" at another location where they would be able to communicate with the satellite as it passed over their Cold War adversary. On July 9, 1960, the NRL quartet listened in on a relay from GRAB 1. This was the start of the satellite's first collection phase, devoted to "engineering-evaluation." They were stunned by the plethora of signals coming in. It was much richer than the harvest in Hawaii, an abundance that they knew instantly would be a blessing and a curse.¹⁸

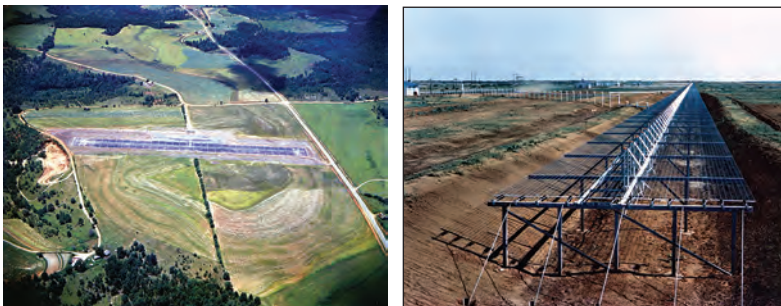
And all of this detection was in the context of one radar band, the S band. "GRAB was successful but we knew there were other Soviet radars at different frequencies and we were only able to detect the ones that were at S-band," Wilhelm commented much later. "When we tried other frequencies [in later programs], Voila!, they've got more."¹⁹ But that wider surveillance sweep would have to wait.

The technological capability was coming into place faster than was the ability to manage it and establish a command structure that went all the way to President Eisenhower. A top secret schedule for the first official collection phase was sent from

the NSG to the White House. “Chop chains”—rosters of people in the loop at the CIA, Defense Department, State Department, and elsewhere—were established. By the time this authority structure was in place, the aforementioned engineering-evaluation phase between July 9 and 21, which to the NRL team essentially was a test phase, was almost over. The results were good and tantalizing enough that the Secretary of Defense sent a letter to the President on July 20 reporting that the time had come when the President could authorize missions over the Soviet Union.

When the President sent his approving initials on July 25, the test phase tapes with intercepted Soviet signals from 11 overpasses already were en route to NRL by military courier. For the second collection phase, the more formal tasking and authorization procedures would be in place.²⁰

The summer of 1960 was a banner year for Navy missile and space endeavors, especially for NRL. In addition to the promising start of the GRAB program, the nation’s first ballistic missile nuclear submarine, USS *George Washington*, launched a pair of Polaris missiles while submerged; the Naval Space Surveillance System (NAVSPASUR), a direct descendant of the Minitrack system from the Vanguard program, was continuously tracking every object that humanity had so far placed into orbit; and Communication Moon Relay, an NRL project to exploit the moon as an electromagnetic mirror for long-distance radio communication, was inaugurated, allowing for a new and reliable channel for transmitting messages, including facsimiles, between Hawaii and Washington, DC, for four to eight hours each day.



Space Surveillance in the Heartland. Shown here are aerial and close-up views of two of the massive antennas of the Naval Space Surveillance (NAVSPASUR) system (left: near Lake Jordan, Alabama; right: near Lake Kickapoo, Texas). NAVSPASUR grew out of the Minitrack system that NRL engineers built during the Vanguard program. (NRL photos 60644(3D).jpg and 61735.jpg)

At the same time, analysts back at NRL in the signals processing section of Lorenzen’s Countermeasures Branch began receiving packages from the GRAB huts around the world. Initial screens of the tapes provided an exciting yet sobering inkling of how vast the bounty from GRAB 1 was likely to be and how challenging it would be to make sense of the deluge of data.

“[The data analysts] were accustomed to looking 50 to 200 miles into the Soviet Union from some vantage point from the ground or from an airplane,” Mayo said, referring to traditional ferret missions. “Here, suddenly, they were able to see 3,000,

3,500, and 4,000 miles! The magnitude, the massive quantity of signals that were available in one short instance in time, was staggering. They were just unprepared for the millions and millions of pulses they received.²²¹

“Bob Misner had the job of analyzing the tapes,” Wald recalled. “Initially he sent the signal output into a bank of narrow-band frequency filters, with the output of each attached to a pen that made a mark on a roll of wet electro-sensitive paper. The position of the marks across the width of the paper gave an approximate indication of the pulse repetition frequency (PRF) of the intercepted radar. The distance between repeats along the length of the roll indicated the rotation period of the radar’s antenna.”²²² With specific traits like these, ELINT specialists stood a chance of categorizing intercepted signals as coming from already known Soviet radar equipment or from systems the U.S. had not known about before.

There would be no way that earphone-wearing analysts in the huts, or even chart-reading analysts at NRL or the National Technical Processing Center, would be able to make much sense or use of the vast amount of ELINT signals GRAB 1 was intercepting. Recasting the signals into charts that rendered them visible helped somewhat in determining the density and east-to-west distribution of radars across the Soviet Union, but it was obvious that data management and analysis could well become the most challenging aspect of ELINT from space. It was like looking at all of the paintings in the National Gallery in an instant rather than taking in one work of art at a time. Automation and computers would have to be integrated into the systems as soon as possible.

On September 28, 1960, the NRL team lost contact with GRAB 1 as they attempted to undertake a third phase of data collection. The operating life of the world’s first spy satellite had come to an end. In its three-month lifetime, President Eisenhower had approved 22 ELINT collections with the satellite. The initial success of GRAB—mostly as a proof of principle that ELINT collection from space works—meant that the NRL space-based ELINT team now would have a full-time job to improve upon this beginning and to provide the country with ever better orbiting listening posts.

It would be some time before GRAB 2 would be launched, so the NRL signals processing team, led by Misner, drilled into some of the tapes they had received from the collection huts. They were able to identify signals from early-warning radars (the kind that helped the Soviets shoot down Gary Powers’ U-2) and shipborne radar units deployed by the Soviet Union. They also discerned previously unrecognized signals with unique pulse patterns and frequencies. But the biggest surprise was the sheer volume of intercepted signals. The first inclination of the NRLers was to attribute this volume to some combination of (1) a wider-than-expected detection bandwidth, akin to having a larger and finer-mesh net that would catch more fish and more kinds of fish, (2) the Soviet use of higher-than-expected power in their emitters, or (3) a surprising sensitivity of the satellite’s radar-signal interception system. A fourth possibility, which they did not seriously consider at the time, was that the

Soviet Union had been installing a massive air defense radar system.

What was clear is that the satellite worked. Also clear was that the bounty from this new intelligence asset could be lost if some pathbreaking techniques for parsing the massive flow of data were not developed. This is where Misner and his mathematically minded colleagues came in. A starting challenge would be to somehow convert the analog signals captured on magnetic tape into a digital form that a computer could handle. Misner's team was adept with both equations and hardware and the team built a number of one-of-a-kind pieces of analytical equipment. Misner set into motion a system by which the data on the tapes from the huts would be converted by his team at NRL into visual charts before the tapes were couriered to the National Security Agency (NSA). Transcribing the charted format of the data into digital format by way of punch cards turned out to be the most time-consuming step, amounting to about 20 hours per tape. There were 80 tapes in hand from the GRAB 1 intercepts. Once the signals were encoded onto punch cards, Misner knew, his experts and their computers would be better able to wrench out information of potentially strategic and tactical importance.²³

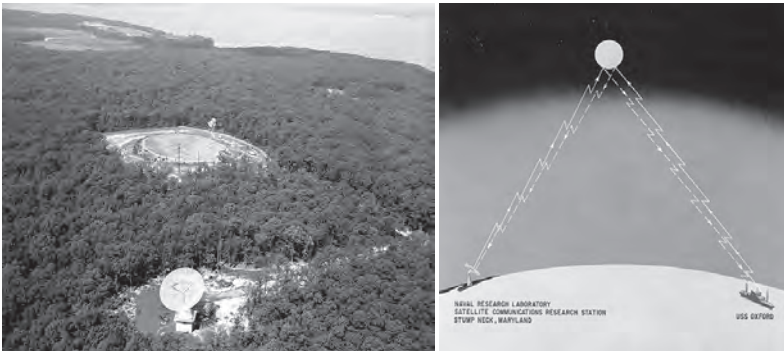
Meanwhile, the national-level analysis team at the NTPC was crying uncle. It was overwhelmed by the volume of data and asked the NRL team if it could, in Mayo's words, "turn down the gain," which was their way of asking if the intercept receivers could be made less sensitive.²⁴ The analysts did their best and set their priority on novel signals they had not seen before and in teasing individual signal patterns out of the cacophony so that they could precisely characterize specific types of radars. It was the sort of ELINT data that could help the Omaha, Nebraska-based Strategic Air Command (SAC) integrate the Soviet air defense radars—whose threat was sorely felt in the downing of Gary Powers' U-2 jet—into its own flight plans and other tactical considerations. In the event that World War III began, SAC would strive to set flight plans for its Stratojet and Stratofortress nuclear bombers that would thread around the purview of Soviet radar installations.

Secretary of Defense Gates liked what he was seeing and told President Eisenhower the same. On October 17, 1960, the President gave NRL the go-ahead for another GRAB satellite.²⁵ Secrecy remained so tight that the GRAB program remained unmentioned in the Secretary of Defense's classified quarterly reports.

About a month after GRAB 1 stopped working, there was a scare that the worst had happened. The Kremlin warned the U.S. that it would respond to any attempt at espionage from space "as successfully as it had done with respect to air space," referring to its May 1 downing of the U-2 photoreconnaissance jet. The timing of the warning made everyone nervous.²⁶ Was it possible that the Soviets had detected GRAB 1 after all? With more detailed data regarding the satellite's trajectory and the amount of time that detectable and associated RF signals were in the air, Lorenzen's crack analysis team determined that the likelihood the mission had been compromised was negligible.

Even without direct knowledge of the GRAB program, the Soviet defense community knew the U.S. would be working hard to add space-based intelligence-gathering assets to its airplane-based ones. And the Soviets, who were working toward their own fleet of ELINT satellites,²⁷ already had been accusing the U.S. of orbiting reconnaissance hardware.²⁸

With a Presidential green light for GRAB 2 and little reason to fear that the Soviets had caught onto the program, it was full steam ahead for NRL's GRAB team. For his part, Misner directed Wald, who had been working on automated signal-processing techniques for another highly classified project, to help solve the data-analysis challenge that came with GRAB's massive flow of radar data. On hand for the task was the Naval Research Laboratory Electronic Digital Computer, or NAREC.²⁹ It was a room-sized, electricity-guzzling, vacuum-tube-based behemoth. The lab acquired the state-of-the-art machine a few years earlier to help parse signals collected at a massive 200-foot parabolic antenna dug into the ground at Stump Neck, Maryland. The massive dish was built to determine if signals bouncing from the moon could be received with enough strength to be useful for naval communications with vessels at sea and for listening in on Soviet RF emissions. Meanwhile, parallel efforts by ELINT specialists at NSA and elsewhere were devoted to figuring out how best to manage, interpret, and use these new lines of intelligence.



Moonbounce. In the 1950s, an NRL engineer conceived of a long-distance communication system in which a transmitter would bounce signals off the moon, which then would be picked up by the receiving antenna. Shown here is one realization of the moon relay, or moon bounce, concept in the form of a 1.1 acre receiving antenna at NRL's communications station in Stump Neck, Maryland, as it was in 1958. Until 1957, it was the largest parabolic antenna in the world. The illustration shows how the signal relay would go between a representative Stump Neck antenna, the moon, and a ship at sea. (*NRL photos 58-040250.jpg and 61336.jpg*)

“I was assigned the task of automating the process,” Wald recalled, before continuing to describe the role that he and his wife, Bets Wald, who was also a mathematically trained NRL colleague, played. “We digitized the tapes, and Bets and I wrote a NAREC program to deinterleave coincident pulse trains and identify the number of radars seen while accurately determining the PRF [pulse repetition frequency] of each. We called our effort Project Eyestrain, an oblique reference to the manual method we were superseding.”³⁰

Under the supervision of Dix, the Satellite Techniques Branch had been working hard to refurbish the leftover GRAB 1 twin, the one with the cracked solar panel and other injuries, into flight worthiness. On November 30, 1960, just six months after GRAB 1 had become the world's first spy satellite, GRAB 2—again sharing a single metal shell with a scientific cover payload dubbed SOLRAD 2—hitched a ride skyward with APL's Transit 3A satellite. But 12 seconds before it was supposed to finish burning, the primary stage of the Thor Able Star rocket fizzled out. In that moment, what the public thought was supposed to have been a launch of another Transit satellite for the Polaris program and a second SOLRAD satellite to study solar-ionosphere interactions, became an unguided missile that happened to be headed toward Cuba. In it too was the would-have-been GRAB 2 payload. The range safety officer knew something had gone wrong and triggered a self-destruct sequence. Even so, debris from the vehicle rained down on the Cuban countryside, about 10 miles from Holguin, then Cuba's third largest city.³¹

The Prime Minister of Cuba, Fidel Castro, cast the incident as an act of imperialist aggression. Following rumors that some cows had been killed by the debris, a mock-up of a Thor intermediate range ballistic missile with the acronym USAF stenciled on the side was paraded in the streets of Havana as a cow-killing Pentagon rocket. There would be no more launch trajectories over Cuba.³²

With any new ELINT data from the GRAB program delayed at best, the participants in the program decided to take a closer look at the data already collected in the 22 missions GRAB 1 had completed. It was clear to analysts from NRL, the Naval Scientific and Technical Intelligence Center (in Suitland, Maryland), and the National Security Agency that the data was vast enough that it would take new techniques, including automated methods using computers running well-designed algorithms, to eke out valuable information from it. Lorenzen had been worried that the program would lose favor by those who had authority to cut it off, but on December 14, 1960, NRL received heartening news from the GRAB program's sponsor, the Bureau of Weapons (BuWeps). The Bureau informed Lorenzen's team that "the tremendously successful project will be continued." In 1961, the Department of Navy provided \$3 million for that continuation.³³

With this fresh support and money, NRL's GRAB team kicked into a higher gear. Mayo and Rose designed a more capable ELINT payload that could listen in on a wider range of radar frequencies. Pete Wilhelm made corresponding changes in the data transmitter while others in the Satellite Techniques Branch worked with vendors on components or investigated commercial options for recording devices that would enable the satellite to store more data before relaying it to a receiver on the ground.

The issue of how to manage the deluge of ELINT data so that it actually would be useful and actionable emerged as the issue of most concern and it would presage similar challenges for large-scale ocean-surveillance systems that NRL would help

develop in the future. At the time, in the early 1960s, Misner and his colleagues still were converting magnetic tape recordings of the raw data into visual readouts from which individual pulse patterns, scan rates, and illumination durations might be more easily discernible. But given the volume, or density, of intercepted radar signals, that procedure was impractically laborious and time consuming. Taking on this so-called “density problem”—as the troublesome abundance of signals was known by insiders—entailed that the analyses would have to be heavily automated and Wald would be one of NRL’s principal early innovators in that endeavor. Misner also was taking on the data management problem, including looking into better ways of converting visual data into digital format and of developing new techniques in magnetic recording that could make the raw data easier to work with. But all of that would take time and this was an era when national leadership was impatient to know more about Soviet military capabilities.

Everyone who had access to the data knew that the United States now had in hand a remarkable new means of intelligence gathering, but the situation was akin to being locked outside of an overstocked chocolate shop. There was so much desirable product inside that it essentially was blocking the entrance. In a January 10, 1961, letter to Fred Hitz of the Navy’s ELINT program, Fred Weldon of the Office of Naval Intelligence (ONI) summed up his assessment of the program for the Omaha-based Strategic Air Command and other end users this way: “It is already obvious that the results from GRAB will have a direct and significant bearing on the consolidated targeting and war planning effort at Omaha³⁴ as well as upon strike force tactics, weapons, and [electronic warfare] hardware. We owe it to national security to release our tentative results—to the extent they are valuable and of reasonable reliability—as soon as we can ...”³⁵

At NRL, Lorenzen ramped up the data reduction effort. It was NSA’s charge to develop the means for direct digitization of GRAB tapes—a task then referred to as Audico, short for audio-to-digital conversion—rather than the tape-to-chart-to-punch-card route that had been for the NRL team the primary way to bring computers into the mix.

Remarkably, this work-in-progress was getting implemented on the fly. The collection huts that received ELINT data from the satellite, for example, were all refitted with upgraded recorders (Type GR-2500) from the Consolidated Electroynamics Corporation, a Pasadena, California, subsidiary of the Bell and Howell Company. The mobilization of talent at NRL was intense. Wald, for one, made sure that the manual conversion of burst records for digital processing with the NAREC continued. The Ph.D. mathematician Bassford Getchell helped Wald in writing programs that could identify actual signals among the noise in the GRAB data; discern pulse, timing, and other patterns in them; and even infer the general location of the sources, that is, the Soviet radar installations.

The profile of NRL's ELINT satellite program continued to ascend. It became a priority for Director of Naval Intelligence Rear Admiral Vernon Lowrance, a World War II submarine commander. In a letter dated January 27 to NRL's Commanding Officer, Captain Arthur Krapf, Lowrance praised Lorenzen and his team, even as he pressured NRL to speed its efforts at analysis and data processing.³⁶ In a sign of just how coveted the information from the GRAB program was becoming to the country, the Strategic Air Command, or more specifically SAC's 544th Technical Reconnaissance Group at the Offutt Air Force Base in Omaha, Nebraska, was given permission to take steps toward developing its own analyses of the data. The goal was for SAC to include ELINT data in its work to reveal the Soviets' "radar order of battle," which in turn would inform targeting, air routes, and development of other tactical details for SAC's fleet of long-range bombers.³⁷ The radar order of battle refers to, in this case, the locations and capabilities of all Soviet radar systems on an ongoing basis.

When NRL was immersed in Project Vanguard, and GRAB was little more than a concept scratched out on a Howard Johnson's paper placemat, the Air Force and CIA were orchestrating audacious intelligence programs using advanced aircraft and rockets. Among them was a film-return mission, which became known as Corona, in which camera-bearing satellites would take high-resolution pictures of Soviet territory and then drop film-containing canisters back through the atmosphere where they would, ideally, be snatched in midair by Air Force personnel flying modified cargo aircraft. After a dozen straight failures, and following one ship-based recovery, the first successful Corona air recovery took place on August 19, 1960.³⁸ That was two months after GRAB 1 made it into orbit as the world's first spy satellite.

The secret intersection points of intelligence and space had been proliferating, most often in parallel, each with its own innovators, champions, history, and technical, command, and oversight infrastructures. It was an unwieldy process, prone to duplication and/or competition, and it was expensive. But the successes of GRAB and Corona demonstrated that these and other advanced "national technical means" were becoming integral and important components of national defense.

On Eisenhower's last day as President on January 20, 1961, the Deputy Secretary of Defense, James Douglas, who was Secretary of the Air Force until the sudden death of Deputy Secretary Donald Quarles in May 1959, circulated a memorandum to the Director of the National Security Agency and all of the military departments' secretaries about how space-based intelligence would be controlled. It wasn't good news for the Navy and it did not bode well for NRL's GRAB team. The Air Force emerged as the nation's lead administrative body for the country's overall reconnaissance program and so likely would have decision-making power, or at least strong influence, on what the Navy would be able to do in space. When it came to COMINT (communications intelligence) and ELINT (electronic intelligence), all efforts were to be coordinated through the NSA. The day after the memorandum was issued was the first day of the administration of the nation's new President, John F. Kennedy.

Kennedy's appointee for Secretary of Defense, Robert McNamara, resigned his presidency of the Ford Motor Corporation and arrived at the Pentagon with a background, mindset, and skill set that would change the way military programs, including ones like GRAB, would be carried out. Seat-of-the-pants approaches would no longer dominate. McNamara overhauled the administration of the Department of Defense's many small and large elements, from stem to stern. He placed a heavy emphasis on cost-effectiveness for all programs.³⁹

Seven weeks into his tenure, McNamara signed DoD Directive 5160.30 by which the Air Force again came through as a primary decision authority regarding whether space systems ultimately would move from planning and development phases toward completion and deployment. The mandate wielded a blow to the space technology development culture that the Navy had created and hoped to perpetuate. The Air Force approach generally was to call on the scientific community and to contract with industry to develop systems, while the Navy turned to its bureaus (such as BuAer and BuWeps) and used government laboratories as performers in addition to the contracted support it got from industry and academia. With the Air Force in the pilot's seat, however, the Navy's space programs were likely in for changes. Add to that the cost-mindedness that a former leader of the country's automotive industry was bringing to Department of Defense decision making, and switches were set for high anxiety among NRL's space cadre.

Despite the success and praise the GRAB program had earned, the follow-on technology that Lorenzen, Mayo, Wilhelm, and their GRAB teammates now were developing would likely be stifled in the new, more bureaucratic context that McNamara was bringing into the Department of Defense. Pivotal here was the practice of NRL's satellite builders to conduct and manage their own R&D—doing most of it in-house with in-house talent—and then build their own satellites (again in a mostly in-house operation) based on that R&D. McNamara's approach threatened to undermine this mode of operation because it decoupled R&D from technology acquisition.

As it turned out, McNamara had not been briefed about GRAB. He knew nothing about it. To the Secretary of the Navy, John B. Connally, that knowledge gap actually opened an opportunity to convince McNamara that he needed to reconsider how he was thinking about the Air Force as the lead service for all Department of Defense space programs and about how systems were developed and acquired. Connally arranged for a briefing team to tell the GRAB story directly to McNamara in the SecDef's own office. The upshot was that the Secretary of Defense commended the program, but he still wanted accounting data as a basis for his own decisions about the program. This meant that Lorenzen and his GRAB team would have to conduct a rigorous cost analysis.⁴⁰

Meanwhile, Rear Admiral Thomas Connolly, then with BuWeps (the Navy's administrative support center for the GRAB program), got to work on the bigger challenge of convincing McNamara to reconsider the Department of Defense space

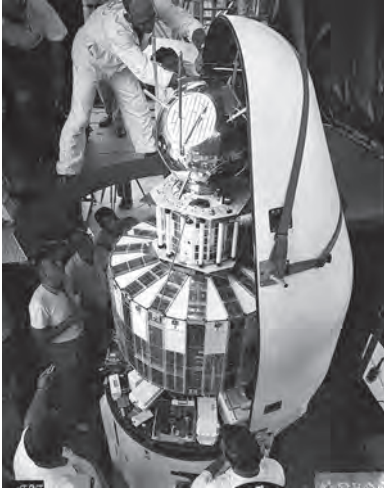
directive. His suspicion was that McNamara had been moved by concerns about duplication, waste, and mismanagement without also considering the actual capabilities and payoff that had emerged from the ELINT program NRL had conceived of and led over the past three years. Rear Admiral Connolly was concerned that the subordination of the Navy's role in space to that of the Air Force's could hamper the Navy's ability to develop the spaced-based technologies that would become important for national defense. So Rear Admiral Connolly drafted a confidential memorandum for the Secretary of the Navy that he hoped would ultimately help to get McNamara to reconsider the nation's military space command protocols.

Ironically, the GRAB program had remained viable partly because it was deeply black enough to glide along under almost everybody's radar screen. Even amidst the top-level maneuverings, preparations for another GRAB launch were well under way. Wald and others focusing on data management, digitization, and computer analysis were taking significant steps in tackling the density problem. Others in the countermeasures group made upgrades to the collection huts, including taking care of habitability problems by adding air conditioning and sun shades. Lorenzen and Mayo assembled a 15-member launch team among their NRL colleagues with Dix from the Satellite Techniques Branch and Mayo from the countermeasures group as leaders. Meanwhile, for their part in moving toward automation and higher-volume analysis, NSA's analysts and researchers were developing and testing algorithms and specialty computing equipment.

The reality check on the program was that heretofore only one GRAB satellite had flown and had collected data only on 22 President-authorized occasions. There had been no new data since GRAB 1 stopped functioning. Meanwhile, the Strategic Air Command had urgent need of building all available and reliable ELINT data into its own tactical planning. There was a sense by many at the time that World War III could start at any moment and so vigilance and intelligence were of utmost importance to national security. This spurred efforts to transfer to SAC more of the digitized data from GRAB 1, as well as emerging data analysis tools and techniques, including ones that Misner and Wald had been developing at NRL. Toward that end, Wald and Getchel developed a computational format that became the common one for digital tapes no matter where the ELINT analysis was being done. At the same time, more players, particularly from the Air Force, were requesting and receiving clearances to get inside the GRAB loop just as the program was about to take off again, literally.

On June 29, 1961, atop a Thor Able Star rocket, a trio of satellites was launched into orbit. A threesome launch had never been done before and there was a problem. The primary payload, the Transit 4A navigation satellite, designed and built by the Applied Physics Laboratory, made it into its intended orbit. But the GRAB 2 payload, along with its SOLRAD 3 co-payload, failed to detach from the third satellite, a scientific platform dubbed Injun, which was designed by Professor James Van Allen of the University of Iowa to conduct measurements of the radiation belts named after

him and that were first discovered with instruments aboard Explorer 1, the country's first satellite. The failure of GRAB 2 and Injun to detach was due to a mistake on the ground in the sequence of command signals sent to the satellites. Even so, and despite the inability to operate both satellites at the same time due to electromagnetic interference, both satellites were able to carry out at least part of their respective missions. That was achieved by alternating the days on which they operated. GRAB 2 began collecting ELINT data over the Soviet Union on July 15, 1961.⁴¹



Space Triplet. With that spherical style of NRL's early satellites, the twin payloads of GRAB 2 and SOLRAD 3 (housed in the same shell) are mated with the University of Iowa's Injun satellite, which is mated to the Applied Physics Laboratory's Transit 4A navigational satellite. The triplet was boosted into orbit on June 29, 1961. (NRL photo 60370.tif)

In short order, the new GRAB data was duplicated and couriered to NSA analysts. Again, the sheer volume of data proved overwhelming, especially as related data from other new SIGINT assets also began pouring in to the same human resources. Top leadership at the NSA and Office of Naval Intelligence that had been involved in the GRAB program was undergoing changes, as also was the organization and command structure within NSA. But the program itself and its intellectual and technical parents at NRL—among them Lorenzen, Mayo, Misner, and Wald—remained as constants. As the new director of ONI, Captain Donald Mac Showers took over, Lorenzen, always looking ahead, handed him a plan for three heavier and more capable GRAB satellites for launch in 1962.

The Strategic Air Command had managed to go further than any other player in converting GRAB data into operationally useful information and guidance. This was due, in large part, because of its focus on those ELINT signals for which it could determine an associated radar's position, but only on the portion of these signals that also would be relevant to the country's current SIOPlan—Single Integrated Operational Plan—for World War III. SAC's approach almost certainly was manual and brute force using charted versions of the raw data from the magnetic tapes. Even so, SAC managed to develop at least a rough Soviet radar order of battle more quickly than NRL or NSA analysts did.

To render the incoming GRAB 2 data useful in a more timely fashion, NSA concluded that it should do the dubbing of the raw tapes instead of NRL. Lorenzen thought this could only work if NSA replicated the hardware and software the NRL team had been using and by making sure the links between manual analysis of data and machine processing was as well thought out at NSA as it was at NRL. All of this caused hand-wringing, the drafting of memoranda, and myriad debates in different circles. But all of that would be overshadowed by the most massive reorganization in the intelligence infrastructure to date.

In the late summer of 1961, to consolidate the parallel efforts in satellite-based reconnaissance that had been taken to various degrees of planning and completion, Secretary of Defense McNamara drew up top secret plans for a National Reconnaissance Program (NRP) that would be managed through a new intelligence agency called the National Reconnaissance Office (NRO). The target startup date was mid-1962, less than a year after McNamara circulated the formal memorandum to the military service secretaries. Heading the office would be Richard Bissell,⁴² a CIA deputy director for plans, and Dr. Joseph Charyk, an Air Force undersecretary. Though covert, the NRP would have unclassified designators. For example, the NRO head office would be identified as the Office of Missiles and Satellite Systems (SAFMS) and would reside within the Office of the Secretary of the Air Force.⁴³

The Cold War threat driving these institutional creations was the discovery of radar systems near Lake Balkhash in Kazakhstan during the April 1960 U-2 photoreconnaissance flight, as well as other suspected construction sites for radar installations apparent in the photographs from the Corona film-return space photoreconnaissance mission. The images, coupled with the ELINT data from GRAB and other SIGINT sources that tapped into the actual operating signals of Soviet radar systems, indicated that the Soviet Union was building up a defense system against the submarine-carried Polaris ballistic missiles and the country's emerging cache of Atlas ICBMs (intercontinental ballistic missiles). "A crash program, similar to the Manhattan Project, was needed to detect, analyze, and counter signals from these radars and to find other ABM [anti-ballistic missile] sites in the Soviet Union," wrote Potts, the NRO historian. That is where the NRP would come in, for both photoreconnaissance and ELINT.⁴⁴

The emerging protocols, including a separation of ELINT collection and processing tasks into the control of NRO and NSA, respectively, ostensibly diminished NRL's place in the very ELINT system its staff had invented and built into an important intelligence-gathering tool in the country's tense standoff with the Soviet Union. With the improving portrait of the Soviet anti-ballistic and air defense radar systems, and with great concern about its extent, the urgency of more and better ELINT took a higher pitch among the nation's defense leadership.

One indicator of the ELINT program's status by the nation's top decision makers was that a Thor Able Star rocket that had been assigned for a September 29, 1961,

launch of another Transit satellite for support of the Polaris submarine fleet was diverted instead to launch an intelligence satellite.⁴⁵ Another indicator was that the previous Canes security system for the GRAB program was tightened yet more and renamed as the Hold control system. Meanwhile, the growth and reorganization within the nation's intelligence infrastructure brought with it obfuscating office designations—such as “composite support branch” and “fleet support section” at the Defense Intelligence Agency—that would add additional levels of camouflage.⁴⁶

The official description of the Hold (formerly Canes) program clearly designated the GRAB innovators as continuing on as primary players. The Director of Naval Intelligence was assigned as the Project Director and given overall responsibility of the Navy program by President Kennedy.⁴⁷

Even with all of this apparent prioritization of the GRAB program, and even though NSA at the time was claiming it had achieved a milestone in automated data processing, the growth of overall intelligence-gathering was creating procedural bottlenecks and shortages of mathematicians, programmers, and others with key skill sets. An internal report to the Director of Naval Intelligence also indicated that despite GRAB's technical successes, the NSA, which had priority control over the data, had only managed to produce “two final intelligence product reports” from GRAB data and that there was little reason to believe the productivity would increase in the near future. As such, in the closing months of 1961, despite everything the NRL satellite builders had achieved, the option of closing down the GRAB program was on the table of top-level decision makers.⁴⁸

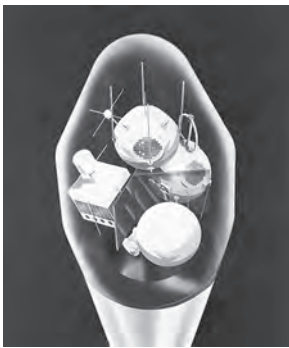
As had become the standard practice, Lorenzen, Mayo, and their confidants at NRL formulated new ambitious plans for the program at the very time when its continued existence was in question. Central among the new plans at NRL was a shift to a two-satellite configuration—what some called a “two-ball”—to improve the system's ability to more precisely locate Soviet radars. This would significantly increase the tactical value of the data.⁴⁹ BuWeps was doing its part as a sponsor by moving the paperwork that would provide the program with \$1.5 million, which was sufficient for the Countermeasures and Satellite Techniques Branches to build the components, systems, and overall satellites. Among the tasks for the NRL crew was to upgrade the ability of the GRAB receivers to cover more of the radio spectrum, a challenge that involved antenna design, power management, miniaturization, and other technical issues.

Wald was set onto the problem of assuring the best way to track the orbital trajectory of ELINT satellites, since knowing the position of the spacecraft was crucially important for the task of precisely locating on the ground the source of an emitter, such as a search radar or anti-ballistic missile radar. In a report to the Technical Operations Group for Program C—as the Navy's part of the National Reconnaissance Program came to be designated—Wald and two computer-savvy colleagues in the

lab's Minitrack and follow-on NAVSPASUR systems concluded that the latter orbital tracking system, of all U.S. space surveillance assets, was best suited for the job.

At the same time, momentum was building to overcome what perhaps remained the hardest problem of all: getting the Department of Defense to procure a suitable launch vehicle. This was a good development in that in early December, 1961, there were signs coming in that GRAB 2's days were numbered. Operators at the receiving huts were reporting anomalous tracking and ELINT signals, indicators that the satellite was losing its health. The communication channel servicing the unclassified SOLRAD 3 mission failed entirely and the classified payload became unable to detect the higher frequency bands that it had been designed to listen in on.

The launch vehicle problem was solved, in part by bundling more satellites onto one rocket than had ever been attempted before. For the next launch attempt, in January 1962, five satellites were bundled into a cluster nicknamed "Buckshot." NRL had three satellites in the group: a 9-pound object, dubbed SURCAL 1, that would help calibrate the NAVSPASUR system; a 60-pound satellite dubbed LOFTI 2A, which would receive very-low-frequency, water-penetrating signals in tests to see if these would also penetrate the ionosphere intact and become a new channel of communication with submarines; and the 55-pound SOLRAD payload sharing the same shell with the next incarnation of a GRAB payload. Along with these satellites was Injun 2, another payload for studying the Van Allen radiation belts, and an Army communications satellite.



Buckshot. Three portraits, including an artist's rendition and a wooden model, of an ambitious and ill-fated attempt on January 24, 1962, by NRL, along with the Army, Navy, and Air Force, to launch five satellites with a single booster. The cluster was named Composite I, but the nickname Buckshot became its more familiar moniker. (NRL photos 60321.jpg, 60325.jpg, and 60327(2).jpg)

On the morning of January 24, 1962, a Thor Able Star booster lifted the cluster of satellites from the launchpad at Cape Canaveral, a brilliant plume trailing the soaring booster. But the second stage, after separating on schedule, exploded, sending the

entire five-satellite payload into the sea.⁵⁰ Three months later, on April 26—a day when NASA and the U.S.S.R. also launched missions into orbit—another attempted SOL-RAD/GRAB launch, this one from a launchpad on the west coast at the Naval Missile Facility at Point Arguello (later to be known as South Vandenberg), also ended in failure, plunging into the ocean within eyeshot of the launchpad.⁵¹

With those failures also went the name GRAB, but not NRL's space-based ELINT project, which was renamed yet again to Dyno. NRL, along with BuWeps, the Navy's sponsor for the follow-on ELINT program, established a launch schedule and budget through fiscal year 1964 involving two launches of two-satellite pairs per year. The re-naming became retroactive, which is why GRAB 1 and 2 were sometimes later referred to as Dyno 1 and 2, respectively. In practice and in time, GRAB became the primary name associated with this pathbreaking ELINT program.

As plans for GRAB progressed, the analysis team at NSA was chugging along on the data backlog from GRAB 2 when they happened onto a mother lode from one of its collections. In a stroke of dumb luck, the satellite's interception equipment happened to be switched on to collection mode on August 6, 1961, when Russian cosmonaut Gherman Titov happened to be in orbit and happened to be experiencing problems while, in Potts' words, "the world anxiously waited news."⁵² Apparently, the Soviets lit up much of their search radar equipment to help push toward a successful recovery of Titov (the second Soviet cosmonaut; Yuri Gagarin was the first cosmonaut and the first human in space). GRAB 2 was there to eavesdrop. These intercepts contributed to a new assessment of the overall payoff of GRAB by the Office of Naval Intelligence. According to Potts, the ONI assessment indicated that "one of the startling contributions of the program has been the discovery of a new radar system thought to be part of the new anti-ballistic missile complex of the Soviet Union."⁵³

That discovery had a direct bearing on the potential wartime effectiveness of Polaris missiles and had the effect of elevating NRL's ELINT expertise to new heights. There now was anxious talk about how to maintain NRL's "engineering excellence" and the possibility of incorporating upwards of 20 ELINT payloads in launches with scientific payloads from NRL's space science group. BuWeps added funds from previous allocations, providing the currency that both Votaw, and his staff in the Satellite Techniques Branch, and Mayo, along with his brethren in Countermeasures, required to move the program forward.⁵⁴

However, launch failures were a problem. The April 26, 1962, launch had failed when a still-under-development Blue Scout rocket, an Air Force booster, lost attitude control and plunged into the ocean. A post-flight analysis revealed the failure was due to an incorrectly installed valve in a fuel line in the rocket's third stage accompanied by an incorrect assumption by Air Force personnel that two devices—a red warning light and a gauge indicating that a hydrogen peroxide tank was empty—were themselves faulty.⁵⁵

In a letter to BuWeps in response to its call for stepped-up ELINT launches, Claude Cleeton, head of NRL's Applications Research Division, wrote that multiple failures of Thor Able Star rockets, bearing the SOLRAD and LOFTI satellites in their payload bays, had placed these programs in a precarious position and the Blue Scout failure only made the situation worse. "For the laboratory to build up enthusiastic support of a large effort on satellite development, the productivity of scientific information must be greatly improved," Cleeton wrote, referring to the need for successful launches and missions that actually produced data. He added that the reliability of both the Blue Scout and Thor Able Star boosters, especially for multi-satellite launches, had to be improved.⁵⁶

Rather than risking another Blue Scout launch in the near term, the plan was to back down from an accelerated launch schedule in order to wait for the availability of a Thor Able Star booster, which failed frequently enough but also had registered successes. Meanwhile, the Air Force's Samos Project—primarily a photoreconnaissance program that would radio imagery data back to receiving stations on Earth rather than jettison canisters of film as in the Corona missions—was getting under way with satellites that also included ELINT capabilities.

In addition, the Bay of Pigs debacle in Cuba back in the summer of 1961, one of the hottest episodes of the Cold War, had elicited shakeups and reassignments in the top echelons of intelligence organizations, including the National Reconnaissance Program, which had by then taken on oversight of NRL's ELINT work. The CIA, which managed and orchestrated the secrecy protocols, renamed the GRAB follow-on program as Poppy and dubbed the new security control system as Byeman. The plan was for NRL to support four Poppy launches per year. Each Poppy mission would feature two satellites flying in a geometry and manner that would allow for improved geolocation of Soviet radar installations. The Assistant Secretary of the Navy for R&D, James Wakelin, was pushing "to expedite further coverage of the Soviet ABM system as well as other Soviet R&D and operational electronics," according to a proposal that the Secretary of the Navy submitted to Secretary of Defense McNamara on May 21, 1962. The proposal called for attempted launches of Poppy pairs during each quarter of 1963 and 1964.⁵⁷

For their part in the country's early intelligence-gathering efforts from space, NRL's satellite engineers and countermeasures experts pooled their skill sets to ferret out information about early-warning radars and other previously unknown radar systems that could have had relevance in ballistic missile, air, and other national defense and military issues. Estimates by the Director of Central Intelligence of success of a U.S. bomber attack on the Soviet Union changed from the time before the first GRAB mission in June 1960 and after data from GRAB 1 and 2 had been analyzed. The early assessment stated that Soviet air defenses would probably lead to heavy U.S. losses, but that a large-scale attack by the U.S. probably still would be able to deliver many

high-yield nuclear weapons to Soviet targets.⁵⁸ The after-GRAB assessment remains classified, but whether the estimate of bomber survivability increased or decreased, the calculated change would have relied at least in part on GRAB data.

In his official history of NRO's Program C, Potts summed up the payoff of GRAB: "GRAB's engineering legacy was on par with its intelligence results. Existing [electronic countermeasures] technology was readily exportable to space applications. Feasibility of intelligence collection by satellite was demonstrated. A platform in outer space could collect as much as all the platforms in the field of view—at a fraction of their cost and at no risk to personnel. The output, initially overwhelming, stimulated invention of machine processing of digitized data using commercial computers. Relatively sophisticated space and ground equipment could be operated by soldiers, sailors, airmen, and civilian technicians. All elements of the community, agencies and departments could participate in collection, processing, and exploitation of the information derived. Intelligence could partner with science, without reducing effectiveness of either payload. Three years after transfer of NRL's Vanguard team to NASA, DoN [Department of the Navy] has resurrected an in-house capability for quick response production of small satellites and ground equipment to meet multiple defense needs."⁵⁹



Team GRAB. Key contributors at NRL to the GRAB program worked within the Satellite Techniques Branch (top) and the Countermeasures Branch (bottom). (NRL photos, GRAB binder, all personnel names available)

Between 1963 and 1969, the country invested each year in the space-based ELINT program as much as it did during the five year period between 1958, when GRAB was conceived of at a Howard Johnson's in Pennsylvania, and 1963, the year in which the second Poppy launch took place. "By whatever name," wrote Potts, "Tattle-tale, Canes, GRAB, GREB, SOLRAD, Hold, Dyno, Poppy—the project was a success and had only just begun."⁶⁰

¹ Ronald L. Potts, *U.S. Navy/NRO Program C Electronic Intelligence Satellites (1957–1977)*, LEO Systems Program Office, National Reconnaissance Office, September 3, 1988, declassified with redactions and approved for release from NRO on June 13, 2012, p. 37.

² Reid Mayo, quoted from NRL-produced video, “GRAB—NRL’s Secret Success in Space,” released in 1998 when GRAB was declassified

³ Bruce Wald, draft of memoir shared with author.

⁴ Robert A. McDonald and Sharon K. Moreno, *Raising the Periscope... GRAB and Poppy: America’s Early ELINT Satellites*, (Chantilly, VA: Center for the Study of National Reconnaissance, National Reconnaissance Office, September 2005).

⁵ NRL’s Space Science Division (SSD) has earned itself a solid place of historical significance in the history of science and technology. X-ray and Lyman-alpha sensors on the first SOLRAD mission verified sounding rocket indications that shortwave radio fade-out was caused by solar X-ray emissions. From 1960 to 1976, NRL’s SOLRAD satellites were the first spacecraft to monitor an entire 11-year solar cycle. As the nation’s longest continuing series of satellite projects dedicated to a specific research program, SOLRAD satellites collected unprecedented data sets for statistical analysis, making it possible to monitor and compare transient events such as solar flares, and recording long-term changes in the whole sun’s radiative output. Moreover, SSD researchers have contributed many instruments to NASA heliophysics spacecraft. For example, NRL’s observations in 1971 on the seventh of NASA’s Orbiting Solar Observatory (OSO) series discovered the existence of coronal mass ejections (CMEs), the science of which SSD built upon in later missions. For example, the SolWind payload (P78-1), launched in 1979, gathered data on 998 CMEs and established a direct connection between CMEs and interplanetary shocks. And later, SSD’s contribution to the Solar and Heliospheric Observatory program verified that CMEs drive major space weather events and geomagnetic storms and also helped explain the relationship between flares and CMEs. There is so much to SSD’s story that it would take a book to convey.

⁶ Peter Wilhelm, interview with NRL Historian Leo Slater, August 29, 2009.

⁷ Wilhelm, interview with Slater, August 29, 2009.

⁸ Peter Wilhelm, quoted from NRL-produced video, “GRAB—NRL’s Secret Success in Space,” released in 1998 when GRAB was declassified.

⁹ Peter Wilhelm, quoted from NRL-produced video, “GRAB—NRL’s Secret Success in Space,” released in 1998 when GRAB was declassified.

¹⁰ Charlie Price’s son, George Price, would later work for the lab.

¹¹ Potts, *U.S. Navy/NRO Program C*, p. 43.

¹² Potts, p. 44.

¹³ “GRAB: Galactic Radiation and Background: First Reconnaissance Satellite,” pamphlet prepared by NRL (revised edition, April 2000).

¹⁴ Potts, *U.S. Navy/NRO Program C*, p. 45.

¹⁵ Reid Mayo, in *Beyond Expectations—Building an American National Reconnaissance Capability, Recollections of the Pioneers and Founders of National Reconnaissance* (Bethesda, MD: National Reconnaissance Office and the American Society of Photogrammetry and Remote Sensing, 2002), p. 135.

¹⁶ Mayo in *Beyond Expectations*, p. 136.

¹⁷ Potts, *U.S. Navy/NRO Program C*, p. 48.

¹⁸ Potts, pp. 49–50.

¹⁹ Peter Wilhelm, interview with author, February 16, 2012.

²⁰ Potts, *U.S. Navy/NRO Program C*, p. 49.

²¹ Mayo in *Beyond Expectations*, pp. 136–137.

²² Wald, memoir shared with author.

²³ Potts, *U.S. Navy/NRO Program C*, p. 51

²⁴ Mayo in *Beyond Expectations*, p. 137.

- ²⁵ Potts, *U.S. Navy/NRO Program C*, p. 52.
- ²⁶ Potts, p. 53.
- ²⁷ The Soviets began their space-based ELINT program in 1960, but did not succeed at placing ELINT satellites (several in the Tselina series) into orbit until 1967. See <http://www.russianspaceweb.com/tselina.html>; http://space.skyrocket.de/doc_sdat/tselina-o.htm; <http://www.russianspaceweb.com/tselina.html>.
- ²⁸ W.A. McDougall, *The Heavens and the Earth: A Political History of the Space Age* (New York: Basic Books, 1985), pp. 257–261.
- ²⁹ D.H. Gridley and B.L. Sarahan, “Design of the Naval Research Laboratory Computer,” *Electrical Engineering* 70, no. 2, (February 1951): 111, doi: 10.1109/EE.1951.6437257, <http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6437257&isnumber=6437242>.
- ³⁰ Wald, memoir shared with author.
- ³¹ Potts, *U.S. Navy/NRO Program C*, p. 54.
- ³² Potts, p. 54.
- ³³ Potts, p. 55.
- ³⁴ Fred Weldon is referring here to the Strategic Air Command.
- ³⁵ Potts, *U.S. Navy/NRO Program C*, p. 56.
- ³⁶ Potts, p. 58.
- ³⁷ Potts, pp. 58–59.
- ³⁸ Robert D. Mulcahy, Jr., ed., “Corona Star Catchers: Interviews with the Air Force Aerial Recovery Flight Crews of the 6593d Test Squadron (Special), 1958–1972” (Chantilly, VA: Center for the Study of National Reconnaissance, National Reconnaissance Office, 2012), <http://www.nro.gov/history/csnr/corona/StarCatchersWeb.pdf>.
- ³⁹ Potts, *U.S. Navy/NRO Program C*, p. 62.
- ⁴⁰ Potts, p. 64.
- ⁴¹ Potts, p. 64.
- ⁴² Richard Bissell played pivotal roles in the conception and management of the U-2 spy plane program in the 1950s and its follow-on reconnaissance aircraft program in the early 1960s that led to the SR-71 Blackbird.
- ⁴³ Potts, *U.S. Navy/NRO Program C*, p. 74.
- ⁴⁴ Potts, p. 74.
- ⁴⁵ Potts, p. 75.
- ⁴⁶ Potts, p. 77.
- ⁴⁷ Potts, pp. 76–77.
- ⁴⁸ Potts, pp. 77–78.
- ⁴⁹ Wald, memoir shared with author.
- ⁵⁰ Potts, *U.S. Navy/NRO Program C*, p. 80.
- ⁵¹ Potts, p. 82.
- ⁵² Potts, p. 81.
- ⁵³ Potts, p. 81.
- ⁵⁴ Potts, p. 82.
- ⁵⁵ James Winkler, memoir shared with author, page 10.
- ⁵⁶ Potts, *U.S. Navy/NRO Program C*, p. 82.
- ⁵⁷ Potts, p. 83.
- ⁵⁸ Potts, p. 85.
- ⁵⁹ Potts, pp. 85–86.
- ⁶⁰ Potts, p. 86.

10

DOUBLING DOWN: POPPY

Little was known about how the establishment in September 1961 of the National Reconnaissance Office would change the administration and execution of NRL's activities in the Poppy program. What was clear was that the NRO's focus would be on rockets and satellites, the hardware. Also clear was that the funding, budgeting, and programming roles that the Bureau of Weapons (BuWeps) had played in NRL's ELINT satellite program would be taken over by the Office of Missiles and Satellite Systems within the Office of the Secretary of the Air Force (SAFMS). This was the NRO office, hidden within the organizational structure of the Air Force, which was at the top of a top-secret Navy program manned by Navy personnel.

Even as the center of balance of the Navy's program began to shift to a national context for oversight, Navy brass played the role of the hovering parent. "Project Poppy is entering a new phase of operations beginning in November [1962] when the first two-ball will be launched in orbit," the Director of Naval Intelligence (DNI), Rear Admiral Vernon Lowrance, wrote to the head of the Naval Security Group in a letter, dated July 20, 1962, which outlined increased requirements for the project. "Two-ball" was insider-speak for a two-satellite system that would be better than the single GRAB payloads at locating radar emitters in addition to determining their RF characteristics. Wrote DNI Lowrance, "This will be the first launch for the Navy under the auspices of the National Reconnaissance Office and it is desired to maintain the same high degree of performance we have had in this program in the past."¹

For one thing, each ground site now would require two receiving huts and additional sets of trained personnel to operate them. The President's Science Advisory Committee (PSAC) had examined improved capabilities that could come from the additional data of a two-satellite approach, combined with powerful new computers and machine processing techniques. Mathematics, algorithms, and programming were becoming as important as the hardware.

In this same summer of 1962, the NRO took on a form that it would have for several decades. Its primary organizational compartments would become known as Programs A, B, C, and D, respectively.²

Program A centered on Air Force programs in overhead reconnaissance, which included SIGINT components. The program would be managed out of the Air Force Space and Missile Systems Organization (SAMSO). Program A also would have the cross-cutting responsibility of procuring the boosters to get all NRO satellites into orbit, regardless of which lettered program they were part of.

Program B subsumed aerial and satellite photoreconnaissance, such as the U-2 and Corona programs, respectively, which had been and would continue to be managed and sponsored by the CIA.

Program C, under the direction of DNI Lowrance, was the continuation of the Navy's ELINT program known by code names Dyno (GRAB) and Poppy.

Program D, managed by the Strategic Air Command (SAC), focused on aerial reconnaissance over adversaries' territories but also subsumed SAC's analysis of ELINT data, including that collected from NRL's satellites, for determining flight plans for the nation's fleet of strategic bombers.

As was the case before NRL's ELINT satellite work became part of the new NRO's portfolio, DNI Lowrance set up a multi-agency Technical Operations Group (TOG). It included specialists in intelligence requirements, rockets and missiles, orbital issues, signal and data handling, field operations, and other technical areas that space-based ELINT entailed. For the Poppy program, NRL's Howard Lorenzen retained his role as the technical director and primary champion on the TOG. And Reid Mayo, a TOG alternate, remained a leading project engineer, especially with respect to the ground-based command, control, and data reception components of the overall system. As before, the National Security Agency (NSA) oversaw the handling, processing, interpretation, and packaging of the data. The Naval Security Group oversaw the field station operations, most notably of the command and control huts. Among other military bodies represented on the TOG were the Army Security Agency and the Air Force Security Service to help the Army and Air Force coordinate with the program.

As all of this new infrastructure within the NRO was coming together in 1962, GRAB 2 already had stopped operating and any new ELINT satellite within Program C was months away at least. This meant that NRL would be unable to provide satellite ELINT data throughout an alarming development in the North Atlantic that would emerge as perhaps the most tense and dangerous episode through the Cold War. According to an NRO-released history of GRAB and Poppy, "in the summer and early fall of 1962, the U.S. intelligence community was gathering information on a military buildup in Cuba, by means of human intelligence derived from interviews of Cuban refugees," analysis of shipping traffic by the Office of Naval Intelligence, photoreconnaissance imagery in the CIA's U-2 program (NRO Program B), and communications intercepts from spy ships operated by the Naval Security Group.³

A U-2 overflight of Cuba on October 14 yielded photographic evidence that offensive missile installations were being built. Follow-on high-flying U-2 flights, including one that was shot down, and even more perilous low-altitude reconnaissance missions, yielded more details about a Soviet military buildup in Cuba: medium to intermediate range SAMS (surface-to-air missiles), MIG-21 fighters, Ilyushin-28 bombers, missile guidance and target tracking radars, guided-missile patrol boats, and military personnel. Also detected were up to a dozen Soviet-bloc ships potentially carrying arms toward the Caribbean Sea. The stage was being set for the infamous Cuban Missile Crisis.⁴

In the coming weeks, President Kennedy opted for an aggressive response involving (1) a naval quarantine of Cuba to prevent any further deliveries of military equipment or missiles that could threaten the United States, (2) harassing Soviet attack submarines (which were carrying nuclear torpedoes)⁵ in the northern Atlantic, and (3) preparing for a Marine amphibious assault on Cuba. All of the military services mobilized personnel and assets for a confrontation in Cuba, while the full strength of U.S. strategic forces, including nuclear-tipped ballistic missiles and submarine-carried Polaris missiles, were trained on Soviet cities and military installations. The brinkmanship suddenly eased on October 28 when Soviet premier Nikita Khrushchev agreed to withdraw the weapons he had amassed in Cuba in exchange for an assurance by President Kennedy that the U.S. would not invade Cuba and that the U.S. would lift the blockade.

As the Cuban Missile Crisis came and went at the end of 1962, NRL's Satellite Techniques Branch was amidst a busy and frustrating year. It began with the loss of the multi-satellite "Buckshot," which included three NRL satellites, including what would now be known as GRAB 3. That loss was followed in late April by the failure of the Air Force's Blue Scout booster, which took the last GRAB payload built, along with the SOLRAD 4 payload for measuring solar X-rays, into the Pacific Ocean instead of into orbit.

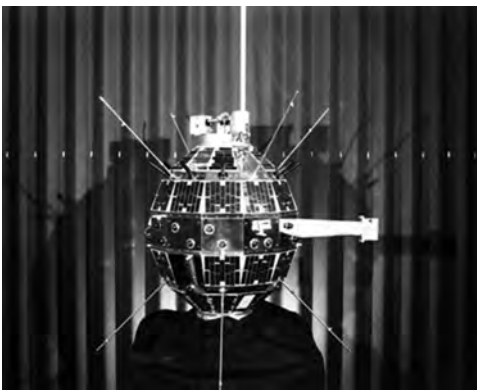
Undaunted, the Satellite Techniques Branch was looking forward to future launches and was continuing to develop new ways of doing things that would become part of NRL's space engineering culture. Engineer Charlie Gorday, for one, was getting fed up with the existing practice of creating comedically long schematic charts of all of the "black boxes" and connectors of a payload's electrical systems and then drawing in lines to represent all of the systems interconnections. So he developed a computerized alternative to represent these numerous electrical connections. James Winkler, a long-time engineer and manager in payload electrical systems, recalled the procedure:

"Charlie informed us that for each contact on each connector, an IBM card must be generated. The huge box of cards resulting were then fed into a computer that, using the special program involved, would produce the desired list. It sounded like a lot of work: first, the engineer or technician designing the [electrical] harness had to fill out many 80-column IBM sheets with the necessary data. Then a clerk would type in the data from the sheet into a cardpunch machine. Then the cards had to be checked (no 'hanging chads') and fed into the computer. There could be no mistakes at any of the steps along the way, but in spite of this and the sheer volume of work involved, we plunged into the effort and, lo and behold, it worked. Charlie's system worked! We would never have to make those ridiculously long harness drawings again... For all our subsequent satellites and spacecraft, this approach was employed. Of course, with the advent of the personal computer, it became possible to type the data directly into the computer and then call for a printout from the same computer."⁶

Winkler recalls another example of innovation, this one by technician Joe Valsi, who was the STB's foremost technician in electrical connections and wiring. Like many of his fellow technicians, Valsi had developed his top-notch skills at the Capitol Radio Engineering Institute (CREI) in Washington, DC. Valsi "had done a lot of research on the latest products available for our applications," Winkler wrote in a memoir. "A major change that Joe introduced into our systems was the concept of crimp connections. There was a general opinion in the branch that crimp connections were not reliable enough for flight systems. Eventually Joe was able to demonstrate that the technology had improved and when proper quality control procedures were implemented, crimp connections would be more reliable than soldered connections."⁷

At the same time, to make sure that soldered connections on the printed wiring boards that went into the payloads were reliable, the STB began sending all of its assemblers to a soldering school, which the young NASA had established and had required all of its employees and contractor employees to attend. "Quality Assurance" (QA) was becoming a common term and a central practice throughout the still young space technology community. It was in 1963 that NRL began what would become a long-term contractual partnership with the high-tech QA firm Assurance Technology Corporation.

Every innovation counted because with the two-satellite architecture, the new Poppy program would double just about everything: the weight of the payload that needed to get into orbit, the number of receiving huts on the ground, the number of personnel trained to operate the huts and handle the data. Each of the satellites also morphed into a stretched sphere of sorts by the addition of a 3.5-inch ring between the two hemispheres, which previously had formed the 20-inch spherical GRAB satellites. Each assembled Poppy satellite now weighed in at 55 pounds.⁸



Mock Poppy. The successor program to GRAB, known as Poppy, ran from 1962 to 1977. Shown here is a model of Poppy 2, the second of seven launches during the program. (*NRL photo Poppy2.jpg*)

Charlie Price, a master of logistics at NRL, including working with foreign authorities, took care of procuring the additional command and control huts and data-receiving (interrogation) huts that the Poppy program required. Price made sure that the two huts at each site, spaced 100 to 150 feet apart and linked with an inter-

com, were upgraded with new receivers for the tracking signal; more capable ELINT data links; and a special 30-foot antenna to receive radio-based time signals that would help analysts of the data to localize detected radar emissions.⁹ To improve the ability of hut operators to tune their receivers, each hut was equipped with the latest oscilloscopes.

Meanwhile, mathematicians and programmers at NRL, under the guidance of Dr. Bruce Wald, supported NSA by streamlining the data processing protocols and adapting procedures for new, more powerful computers. Mayo turned to Don Christman for getting hold of additional recorders—including some of the first ones to be fully transistorized—from the electronic instruments firm Consolidated Electrodynamics. For his part, Lorenzen met with liaisons in London, Paris, and Frankfurt while also managing to make visits to hut sites overseas. New security measures precluded any hut operators from being married to foreign spouses, so some of those who worked on the GRAB program had to shift their services to more conventional (non-space-based) ELINT work. In NRL's main administration building, Building 43, a windowless vault was built for ultrasecure meetings regarding Poppy.

Out in California, at Vandenberg Air Force Base, Marty Votaw, head of STB, worked with partners from the Air Force and the Lockheed Missiles and Space Company to prepare the launch facilities, including a permanent NRL building, Building 660, at Vandenberg's Point Arguello. The first Poppy mission launched on December 13, 1962, just a few weeks after DNI Lowrance had suggested it would go up.¹⁰ Along with the Poppy hardware were two payloads associated with satellite surveillance, one that transmitted specific and known emissions to be picked up by the Naval Space Surveillance System (NAVSPASUR) and one with a known spherical shape whose reflected signal from the space fence could be carefully analyzed. The first of these calibration payloads, SURCAL 2, proved to be more of a problem than a help because its emitter jammed the NAVSPASUR system's receiving antenna for about 10 seconds on each pass until the payload burned up in the atmosphere three years later.¹¹

A partly declassified NRO-produced history of the Poppy program indicates that the ELINT satellites performed well and remained healthy even as the Satellite Techniques Branch was designing the next set of more capable Poppy satellites. Price teamed with Edgar Withrow and other hut experts to prepare additional interrogation huts for new, more eastern locations. These huts would extend coverage for the next pair of Poppy satellites beyond the first Poppy pair's bias for the western and central regions of the Soviet Union. Withrow, along with a small army of technicians and engineers in other administrative units at NRL, took care of this expansion of the hut sites, as well as the acquisition and construction of antenna systems and other components.¹²

As had been the case for the GRAB program, the long period between harvesting the data from satellite receivers over Soviet territory and delivery of that data to end users emerged as a critical shortcoming of the ELINT program. To open up a channel for quicker response capability, the Naval Security Group authorized hut personnel to

“report electronically” any signals with novel pulse repetition frequencies (PRFs) or any other characteristics that seemed unusual. To help with that task, NRL developed additional in-hut equipment for analyzing recorded data and flagging anything unusual.

On June 15, 1963, the next pair of Poppy satellites (Poppy 2), each weighing 85 pounds, was placed in orbit from Vandenberg. These featured 50 percent more solar cell coverage, so there was more power available than before, up to 9 watts, depending on the satellite’s orientation with respect to the sun. Sharing the ride aboard the Thor Agena D booster were four additional NRL payloads: (1) SOLRAD 6, (2) a radiation-counting payload named Dosimeter, (3) LOFTI 2B for the characterization of low-frequency radio communication from space to submarines, and (4) SURCAL 3 for calibrating the Space Surveillance System.¹³

The implementation of “matrix management” helped NRL’s satellite builders to assemble so many payloads in parallel, Winkler noted. “This type of organization was based on establishing a project team with personnel provided by the usual hierarchical organization,” Winkler explained. “To implement this system we would assign an engineer as Spacecraft Manager and two technicians as Spacecraft Technical Managers. After completing their responsibilities at the subsystem level (design, development, and test), the personnel would be involved with the integration and test at the system level. They would then proceed to the launch site and complete the pre-launch checkout of their satellite and assist in the launch and post launch operations.” In the matrix, some personnel would be able to work on several payloads at once, but under the supervision of different managers.¹⁴

In the end, the quintet of payloads launched on June 15, 1963 only lasted about six weeks in orbit. The Thor Agena D rocket that had taken this gaggle of payloads



Team Poppy. Members of the satellite and launch team for Poppy 2 and its four other NRL payloads pose for a group shot at Vandenberg Air Force Base. James Winkler is standing straight in the middle and Peter Wilhelm, with a flat-top haircut, is in the back on the right. (Source: Winkler binder)

into orbit failed to initiate a burn that would have taken the payloads into their intended circular trajectories. Instead, they ended up in an elliptical orbit that cycled them in as close as 95 miles, low enough that atmospheric drag quickly took hold and began to cause their orbits to decay. Though details remain hidden from public view, an NRO history of Poppy suggests that this second Poppy mission yielded a significant piece of ELINT intelligence.¹⁵

As both secret and scientific satellites were becoming more commonplace in the early Space Age, the commercialization of space also was getting under way. Among the most visible developments was the creation of the commercial communication company COMSAT in 1962. It immediately drew upon the talent and players within the existing satellite community, including some of NRL's ELINT satellite pioneers. Among them was Marty Votaw, the man perhaps most responsible for preserving any satellite skill set at all at NRL after the Vanguard team transferred to NASA in 1958. COMSAT hired him away from NRL in 1963 as a project engineer for a then still-conceptual communications satellite program called Early Bird.¹⁶

In August 1963, Ed Dix, whom Peter Wilhelm later rated as “the best engineering teacher I ever had,” stepped into Votaw's shoes as NRL's chief satellite builder for NRO's Program C and as primary liaison with the launch operation at Vandenberg Air Force Base. The Poppy program was growing at this time. The Countermeasures Branch had three major players devoted to the Poppy program and each of them had a team to supervise. Reid Mayo was a ground station engineer while playing the larger role as the overall project engineer. Vince Rose was in charge of the payload. Edgar Withrow focused on the technical task of communicating with the payload from the



STB Bosses. Marty Votaw (left) and Ed Dix, who succeeded Votaw in 1963 to become the second head of NRL's Satellite Techniques Branch, work on SOLRAD 3. The same spherical shell carried an unclassified payload for studying solar X-rays and a classified one, GRAB 2, for spying on Soviet electronic signals emanating primarily from radar systems. (NRL photo 60383.jpg)

ground. Under the supervision of Price were branch engineers who supported Mayo, Rose, and Withrow. Also kicking in here in specific tasks was NRL's Engineering Services Division, which was staffed with skilled machinists and technicians who could take any engineering idea and turn it into hardware.

At the time, the Satellite Techniques Branch consisted of 15 professional staff and 25 technicians distributed among six sections focusing on systems design (run by Pete Wilhelm), structures design (Robert Rovinski), telemetry systems (James Winkler), RF systems (Patrick Cudmore), power sources (Albert Canal), and ground instrumentation (Ralph Gran). Each of these sections and related skill sets would morph, expand, and evolve in the coming decades. During the early years of the Poppy program, the STB had been gaining internal notoriety at the NRO for its cost-effective delivery of satellite systems and often was cited for leverage during negotiations with contractors bidding with high prices for defense aerospace contracts. With Poppy 3 in testing phases and Poppy 4 already in the planning stages, the Poppy program seemed to be in a more stable operational phase than the NRL team had experienced before.¹⁷

January 11, 1964, was a good day for the program. Rather than experiencing another failure, the Douglas and Lockheed teams responsible for the Thor Agena D booster succeeded in getting the Poppy 3 pair into a nearly circular orbit 500 miles overhead from the launch pad at Point Arguello. The Poppy program had been developed with stand-alone classified payloads in mind, but like the old days of GRAB, one of these Poppy satellites hosted a SOLRAD payload, in this case SOLRAD 7A, which, in addition to its scientific mission, once again served as a public cover for the secret payload.¹⁸

The satellites featured an innovation—gravity gradient stabilization—that helped the spacecraft's ELINT antennas to maintain a constant angle toward the Earth. NRL's version of the technique, developed in collaboration with General Electric and managed by NRL mechanical engineer Robert Beal, centered on a deployable, weight-tipped boom whose mass, which is gravitationally attracted to the Earth, enforces a particular spacecraft-to-planet aspect. Bill Collins, Winkler noted, was NRL's boom expert and made sure the systems were reliable yet lightweight enough to be launchable.¹⁹ Wilhelm added that NRL's version of gravity gradient stabilization for orbiting payloads derived from a retractable so-called whip antenna that the Canadian subsidiary of the aircraft company de Havilland had designed for tank communications.

"It was a prestressed beryllium-copper ribbon," recalled Wilhelm. "Basically, if you uncoiled the thing and laid it down on the table, it would fold into a tube." Wilhelm and his colleagues in the Satellite Techniques Branch first used metallic ribbon for making extendable and retractable antennas on their LOFTI 1 and LOFTI 2 payloads—in 1961 and 1964, respectively—for investigating low-frequency communication with submerged submarines.²⁰ "It was a motor-driven beryllium copper tape that laid flat on a spool and as you turned the spool and ran the thing out, the beryllium copper would form into a cylinder and would give you a structurally reasonably strong boom and you could send it out 40 or 50 feet with a mass on the end of it," Wilhelm explained.²¹ The mass would be attracted downward by Earth's gravitation and thereby keep the payload oriented with its antennas facing downward.

“So we took that unit that originally had been a whip antenna and modified it into a structural boom for the gravity gradient stabilization,” Wilhelm said, noting that over time, that innovation, and modifications derived from it, became part of the design of some 40 satellites.²² Because the gravity stabilization systems made sure, in Wilhelm’s words, that “we always were looking down at Earth, we could conserve on the numbers of antennas.” The GRAB payloads, which were not stabilized and spun as they orbited, had to have antennas all around them. In lieu of the extra antennas, Wilhelm noted, NRL’s Poppy team “could pack more electronics into those satellites.”²³

The Poppy 4 satellite set was under construction for a tentative launch date in November 1964. Adding to the challenge was that commercial transistors were becoming available for amplifying radio frequency signals. The shift promised that the satellite receivers made with these would be more sensitive and also capable of being more selective regarding the swaths of the radio frequency spectrum upon which they could eavesdrop. The changeover, therefore, could yield more intelligence about the Soviet Union’s radar order of battle. But it required that NRL’s engineering team make what to Lorenzen was a harrowing shift from tried-and-true vacuum tube electronics.

“Lorenzen was a very old-fashioned guy and didn’t take to new-fangled things very easily,” Wilhelm recalled. “And we had a hell of a time convincing Howard that we ought to get away from the analog and move into the digital. And, you know, Howard—he looked at the number of transistors in these digital circuits, and he counted up the number of transistors compared to an analog [circuit], where there’s very few [parts], and by that simple logic, you know, the analog had to be more reliable. Well, turns out it wasn’t so true ... And on one satellite, to mollify Howard, we actually flew both. And the digital worked just great, never failed, and so there was no looking back after that.”²⁴

Every change in a satellite’s design or componentry, no matter how slight, entails more testing, integration, analyses, and, therefore, time. Even as Lorenzen’s Countermeasures Branch and Dix’s Satellite Techniques Branch worked at their top speeds, the delivery date for the Poppy 4 satellites slipped to February 1965. The Office of Naval Intelligence (ONI) balked at the delay at first and wanted NRL to consider delivery earlier of a less capable satellite package, but Lorenzen convinced ONI leadership that the added capability the fully equipped satellites would deliver was worth the wait. As the NRL engineers assembled the satellites, Vince Rose’s knack for selecting and designing antennas and determining their precise placement was assuring that Poppy 4 would deliver what Lorenzen promised it would.²⁵

In anticipation of the additional data handling and analysis challenges that the next sets of satellites would bring, Lorenzen managed to convince the Office of Naval Research to approve the hiring in March 1964 of two new personnel from the Pennsylvania firm HRB Singer, already well known by Lorenzen for its expertise in electronics for countermeasures technologies. One of them was Lee Hammarstrom,

then a young electrical engineer who had earned a strong reputation for his work in signals intelligence related both to Soviet surface-to-air missile defenses and anti-ballistic missile systems.²⁶ The other HRB hire was a contract technician, Army veteran James O'Connor, who would contribute for many years to NRL's classified satellite programs.²⁷



Fix-it Man. Lee Hammarstrom, shown here in 1983 (years after the Poppy program had run its course) with a globe depicting satellite orbits, played a variety of leadership roles at NRL, as well as with the NRO and other government bodies. He played behind-the-scenes roles in a host of technology development programs thematically connected by the task of moving and processing more bits of data more efficiently, more widely, and with more agility. (NRL photo P-2522(4).jpg)

Hammarstrom found himself in a high-tech candy store of sorts. Among his new boss's deputies was James Trexler. High on Trexler's list was the design and implementation of a 600-foot antenna at Sugar Grove, West Virginia, as part of the overall quest to intercept Soviet signals, including ones from radars deep inside Soviet territory, as they reflected from the moon. Another manager above Hammarstrom, Mack Sheets, was leading a team that was developing high frequency direction finding (HF/DF) capabilities around the globe for tapping into HF signals from ships, aircraft, and submarines deployed by the Soviet Union and other countries. And just about everyone in the branch was working on Poppy, which was proving to be far more successful at collecting electronic intelligence than the GRAB program had been. Even so, the Poppy program was badly in need of modernization in what were the early years of the microelectronics revolution. End users of Poppy data at the National Security Agency and elsewhere were complaining about the data quality, Hammarstrom recalled, adding that Poppy "was not a system likely to survive" reviews by senior decision makers in the intelligence community.²⁸

Hammarstrom would become a pivotal fix-it man for the Poppy system, particularly regarding the ground stations that were as near as Hybla Valley in suburban Virginia and as far away as the other side of the planet. A multi-site overseas trip was quite a trial by fire. "I went through Anchorage, Alaska, just after the 1964 earthquake, then spent days trapped in blizzard-like conditions on the Aleutian Island chain," he recounted. "Later, I was trapped by a Class 4 typhoon that killed a number of people. To top this off, when I was travelling to one of the sites, we were ambushed by people from a Communist uprising; fortunately our guards drove them off."²⁹

The major recommendations Hammarstrom would bring back to Lorenzen were to (1) enact a "crash effort" to equip the stations with computer and other electronic

equipment that would enable trained personnel to locally vet the raw Poppy data so that further processing by SAC or NSA analysts would be more efficient and fruitful, and (2) undertake longer-term and larger-scale rethinking about the Poppy system's overall architecture.

The first recommendation derived from Hammarstrom's direct observations of what he sometimes viewed as reprehensible conditions at the collections huts overseas. "The sites' collections capabilities were degraded by local radio frequency noise from generators and equipment installed after the original 1960 deployments," Hammarstrom recounted. When ordered to do so, operators at the huts would turn on receiving equipment, collect data on tapes, and then have the tapes sent to NSA by secure courier. "Months after it was collected, the people at NSA tried to analyze and process the data by hand or to digitize it," Hammarstrom explained. "Since there were so many things that could go wrong—site noise interference, receivers being mis-tuned, poor tracking, recorders in saturation—not many tapes were useful." He was going to make it his mission to rectify these problems, and then some.³⁰

The more ambitious recommendation to revamp Poppy's entire architecture would get Hammarstrom used to a visionary level of thinking about technology-based intelligence possibilities. More than that, he would later find himself in a position to turn audacious visions into realities, due in part to what amounted to a perfect consilience of projects in his early years at HRB Singer and elsewhere. Those experiences placed him in contact with a slew of individuals who would become powerful decision makers within the defense and intelligence communities. With them, Hammarstrom would in the 1990s help to develop, for example, an intelligence-gathering and distribution system known as the Global Information Grid. It amounted to a specialized big-pipe Internet—suitable for flowing massive amounts of encrypted and highly sensitive data—for the entire defense community, from the Secretary of the Navy to individual warfighters, no matter where they were on the ground or seas or in the sky.³¹

When Programs C's Technical Operations Group³² requested money from NRO to retool Poppy's satellites and ground stations with digital technologies, the head of the NRO at the time, Dr. Brockway McMillan, rejected the request and asked instead for a feasibility study. It felt like a blow to most in the program, but to Wald, it was an opportunity. The study, he was sure, would lead to architectural improvements from stem to stern—from the harvesting of radar-revealing information in the raw intercepted data, to better early identifications of "signals of interest" at field stations, to streamlining the conversion of raw data into digital forms suitable for computer analysis at NSA and other intelligence venues. Wald eagerly took on the NRO request and within a month he had produced a dense, seven-page draft analysis for McMillan.³³

"The new architecture had to be changed so that the sites were not just collectors and forwarders of data, as in the original architecture, but also were doing all

of the ground functions of high quality data capture, storage and processing, as well as dissemination, not only to NSA but other users,” explained Hammarstrom, who also performed an analysis at Lorenzen’s behest.³⁴ His findings regarding the satellites remain classified to this day. As for the ground stations, he concluded they needed higher-gain antennas and signal preamplifiers that could improve the quality of data harvested from the satellites; digitizers and buffering and storage components that could handle higher data rates without losing data or mixing up the sequence of its reception; and computers that could collect data in real time, quickly calculate satellite orbits, process data with sophisticated algorithms, and support dissemination of the data.

The conclusion of Wald’s analysis concurred, noting particularly that essential electronic equipment was not on hand and would not be available for some months. Not one to deny realities, Wald suggested that NRL and NSA immediately begin a joint development program for new technology that would help solve the chronic problem of rendering the torrential flow of raw Poppy-intercepted data into useful information quickly enough to be valuable for strategic and even tactical actions. In short, Wald was challenging himself and his NRL colleagues to leverage the emerging revolution in digital electronics to overhaul the entire data path, from spacecraft to ground station to end users. All of this emphasis on data would become an important driver of NRL’s space technology mission in the decades to come.

The full package Wald and Hammarstrom were suggesting would have to wait for funding, but the analyses spelled out many technical advantages to digitization. And some of the milestones they identified in these proposals were ones that could be achieved stepwise even within existing budgetary constraints. Meanwhile, data from Poppy 3, the mission launched in January 1964, continued to justify the program: though much of its data was noisy and unusable, some of it enabled NSA analysts to identify the function and ability of radar installations that had been imaged via photoreconnaissance assets. In the winter of 1964–1965, Poppy 3 pulled in a particularly rich set of intercepts whose details remain classified.³⁵

On March 9, 1965, the Poppy 4 payloads—two sets of two—shared a ride atop a Thor Agena D rocket with three other NRL-made scientific satellites and an Army satellite for precisely determining specific points on the ground. This group of spacecraft comprised a world record launch of multiple payloads simultaneously. On NRL’s public list of satellite and payload launches, the Poppy payloads are listed cryptically as PL 142 (two satellites), GGSE 1, and GGSE 2. NRL’s other payloads included another in the SURCAL series, another “object identification” test satellite (this one a twelve-sided version called Dodecapole 1), and another in the SOLRAD series (SOLRAD 7B). Two of the Poppy satellites harbored “Gravity Gradient Space Experiments” (GGSEs), which featured retractable, mass-tipped booms that would help keep the spacecraft’s antenna pointing Earthward. Among the other innovations of this Poppy set were “micropound thrusters” that enabled ground controllers to trigger what

some called “mouse farts”³⁶ in order to alter the orbital velocity of the spacecraft with unprecedented precision in response to orbital changes due to, say, subtle atmospheric drag.³⁷ The SURCAL 4 payload provided an orbiting reference for calibration of the NAVSPASUR system. The Dodecapole 1, with a dozen thin booms extending outward so to make the spacecraft look like an orbiting daddy longlegs, served a similar calibration role.

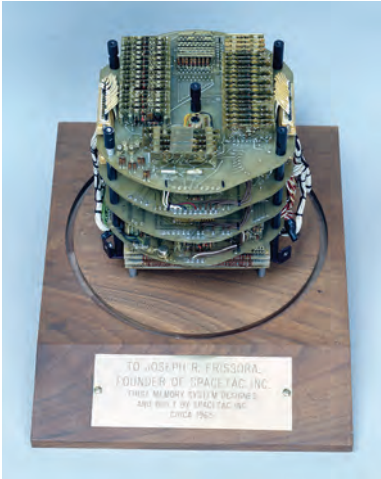


Space Reference. Launched on March 9, 1965, Dodecapole 1 served as a reference target for calibrating the Navy's Space Surveillance System (NAVSPASUR). Once in orbit, a mechanism involving twelve "trap doors" allowed metallic tapes to shoot out and form into 25-foot-long rods about 1/2 inch in diameter, resulting in a space target that was 50 feet across. (NRL photo 77112(14).jpg)

The transmitters of the Poppy 4 satellites had a problem resulting in lower-power signals, it turned out. “This required an immediate redesign and deployment of a higher performance antenna system” at the ground stations, Hammarstrom recalled. A good result that came of this, he continued, was a quicker upgrade than would have happened if the transmitters worked as originally expected. “This turned out to be a big advantage for Poppy when the President’s Scientific Advisory Committee put out its call for a quick response to solve an urgent national need,” Hammarstrom said, without elaborating on that need.³⁸

Adding yet more potential to Poppy were NRL’s SURCAL series of satellites, the Dodecipoles, and other calibration aids that increased the precision with which the NAVSPASUR system could track the ELINT and other satellites. Key here, said Hammarstrom, was the need for orbit prediction to be accurate for several days into the future, a task made difficult by orbital changes due to drag in the thin atmosphere at 500 miles, as well as uncertainty in the amount of drag because of temperature fluctuations as the satellites cycled through sunlight and darkness.

In keeping with its penchant for always moving forward, the NRL Poppy team submitted its plans for Poppy 5 just eight days after the Poppy 4 launch. The plans for this generation of Poppy included improving the solar array system to provide more power, increasing the satellites’ lifetimes, and opening up new design options for the overall payload. Meanwhile, Hammarstrom and others were making ground station upgrades that included latest-generation tape recorders and collection antennas that were steerable remotely by controllers inside permanent ground station buildings, which were major upgrades from the mobile huts.



Pioneer Memory. Built by the contractor Spacetac Inc. at the request of NRL's Robert (Bob) Eisenhower, this unit represents the first solid-state memory unit to fly in space, in 1965, as part of NRL's Poppy ELINT program. (NRL photo P-2346B.jpg)

Serving as a reminder of the larger tidal motions in which NRL was floating, however, the Director of Central Intelligence at this time had convened a committee to evaluate the cost effectiveness of the nation's overhead intelligence collection programs. Lorenzen was on the committee, but its very formation was a warning that past success did not guarantee future funding. Adding to this truism in the mid-1960s were internal reorganizations within NRO and the overall intelligence communities in which authority protocols and other elements of the ELINT infrastructure were in flux.

As these changes were unfolding in the administrative stratosphere, the Poppy engineers at NRL just kept solving problems and improving their ELINT systems. Price and his colleagues, for example, took on the task of replacing receiving antennas at ground stations that could only track in the azimuth—that is, the angle of the satellite from the observation point with respect to a reference direction such as true north—to arrays of antennas³⁹ that could track both the satellite's azimuth and its specific elevation. This made it possible to keep the antennas trained on the satellite for the spacecraft's entire pass. These would help in the pointing and steering of Withrow's new transmitting interrogation antennas and associated electronics that would be installed in phases at ground stations over the next few years. Working to improve the command receiving antennas on the satellite was a team of engineers from NRL and HRB Singer, the firm where Hammarstrom had worked before moving to NRL.⁴⁰

Meanwhile, Wald, along with Lorenzen and Mayo, met on October 18, 1965, with NSA cohorts responsible for converting Poppy data into usable products such as technical intelligence and electronic orders of battle. Digitizing the data in the field was a major topic of discussion. Until the digital approach could be fully certified, however, the program undertook a provisional parallel approach using new digital techniques in tandem with the previous analog procedures developed during the GRAB era a few

years earlier. This assurance phase was necessary, in part, because shifting entirely to digital techniques would entail a then huge step of fitting each field site with state-of-the-art computers, which involved hefty logistics and maintenance support as well as more money.

Along with Wald, Hammarstrom was envisioning the added power and scope that a digital makeover could offer the country's intelligence community. Also on board for this shift was newly hired NRL talent, Fred Hellrich, a freshly minted electrical engineering graduate student from Penn State who happened to have a specialty in ionospheric research, the area that steered NRL into the space business in the first place. In November 1965, Hellrich took his first trip overseas with Mayo to a field station as part of a team installing new receivers and digital equipment.



Poppy Makers. In a side entrance of Building 209 on NRL's campus is a model of electronic intelligence satellite Poppy 3. The Poppy series was partially declassified in 2005. Shown here in 2006 are several of the program's participants. Left photo (left to right): Bob Eisenhower, Fred Hellrich, Vincent Rose, and Pete Wilhelm. Right photo (left to right): Ed Becke, Jim Barnes, and Vincent Rose. (NRL photos DG7Q9837.jpg and DG7Q9849.jpg)

As the Poppy engineers continuously improved components and systems, they began to realize how their orbiting ELINT assets could become valuable to Navy and Army commanders in the field by characterizing and monitoring smaller and even mobile radars and other relevant targets beaming out electronic emissions. At the same time, however, it seemed that Lorenzen was losing some of the contacts and clout he had among higher-echelon decision makers in the Navy and beyond. As organizational structures changed within the government, commanders and managers with less familiarity with the highly classified ELINT systems came into positions of influence and authority. Of most concern to Lorenzen was a set of cost-effectiveness metrics these decision makers were using to rank the value of various assets, including Poppy, in determining the Soviets' electronic order of battle.

"Lorenzen viewed most of the effectiveness metrics as suboptimizations," according to NRO historian Ronald Potts. "It seemed to him the less a system could do, the higher it would score." Also of concern to Lorenzen was the way that imagined projections of the capabilities of future systems, regardless of what their precursors actually had accomplished, were playing into the rankings. This managerial practice,

he worried, could adversely affect the space-based ELINT programs that he and his NRL colleagues had been working on and relentlessly improving since 1958.⁴¹

The nation's overall electronic warfare context continued to get more complicated and so did the portfolio of ELINT payloads from Poppy and other NRO satellites. All of this only multiplied the amount of data that was feeding into the 240 or so NSA engineers and analysts in an office of "Special Projects"⁴² at the agency. Analysts there, and some at SAC, had to accommodate different data formats, calibration protocols, orbital characteristics, and details of ground collection procedures, among other things. "The task was rather like painting a landscape while seated on a moving train," is how Potts described it.⁴³ Amidst this complexity, Lorenzen and other champions of Poppy in Program C's Technical Operations Group would do their best to shift the logic underlying cost-effectiveness assessment to include what they considered to be among the most important parameters for comparison—actual performance gains of Poppy compared to other programs. Among the improvements were (1) on-orbit lifetimes, (2) larger geographic access, (3) expanded RF coverage, and (4) better identification of signals of interest (SOIs).⁴⁴

As the high-level assessment and comparison of the nation's overhead ELINT systems was unfolding through the summer of 1966, Lorenzen's increasingly vocal input strained some relations that previously had been cordial. And there was a cost to this brashness. Funding for follow-on satellite blocks after Poppy 5, which was slated for launch in the winter, was drastically reduced. The program no longer had a strong advocate in the Office of Naval Intelligence, which had been a champion for the program's cause in the overall military and national contexts.⁴⁵

Partly as a morale boost to offset the apparent demotion in the larger intelligence community, and partly because the electronic countermeasure needs due to the Vietnam War were ramping up, NRL's Commanding Officer, Captain Thomas Owen, and the Director of Research, Dr. Robert Page, elevated the Countermeasures Branch on September 12, 1966, to a major laboratory division—the Electronic Warfare Division. Among its branches was one run by Jim Trexler that centered, among other things, on space-based communications. Bob Misner, who with Roger Easton had developed the Minitrack system, headed the Division's new Intercept and Signal Processing Branch, whose engineers and technicians worked on recording and processing development associated with HF/DF (high frequency direction finding). Mack Sheets, another creative RF engineer at NRL, ran the Emitter Location Branch, which would develop direction finding systems for ships and aircraft. In charge of developing new electronic countermeasures (ECM) and for countering enemy ECM systems was Lynwood Cosby in the Defensive Electronic Warfare Branch. Mayo continued heading satellite-based projects, though his effort and team were hidden within Trexler's branch and never identified in lab directories, let alone publicly.⁴⁶

The Satellite Techniques Branch (Code 5170 at the time) was undergoing its own contortions. As had Votaw before him in 1963, Dix left his post as head of the

Branch in 1965 to take a job at COMSAT, the commercial satellite communications firm headquartered nearby in Washington. Filling the sudden leadership gap for the Branch was Peter Wilhelm, who was only seven years into what would become a lifelong career at NRL. He reported directly to Dr. William (Bill) Faust, Superintendent of the Applications Research Division. When Wilhelm took over, the six-section branch had grown to a staff of 54. The section names were as follows: Satellite Systems Integration Section, Ground Instrumentation Section, Satellite Structures Design Section, Electro-Optics Section, Satellite Telemetry Systems Section, and Satellite RF Systems Section.

NRL at a Glance. In 1965, Peter Wilhelm took over the helm of the Satellite Techniques Branch, which resided on the organizational charts (a 1966 version shown here) within the Applications Research Division of the Electronics Directorate. (*NRL Code Directories 1933-2010-231*)

In late 1965, the U.S. Intelligence Board (USIB) put a call out for more intelligence on Soviet ABM/AES (anti-ballistic missile/anti-earth satellite) systems⁴⁷ known as Galosh and Gammon. The USIB identified these systems as top targets for ELINT, and Poppy had been a primary means of identifying and characterizing them. For information about certain emission parameters associated with these systems, Poppy was the only means that NRO had. For Lorenzen, this was a moment in which NRL might regain some of the high ground that it had recently lost in the upper echelons of the decision-making labyrinth.

He managed to get the attention of the technical director of SAFSS—the Office of Space Systems, Office of the Secretary of the Air Force—which, like SAFMS, was

the unclassified name for a high-level NRO office.⁴⁸ In December 1966, in response to a technology challenge posed by the President's Science Advisory Committee,⁴⁹ Lorenzen and Mayo went to SAFSS, classified charts in hand, to make a pitch for how to make Poppy more responsive to emerging intelligence needs. "This was a huge challenge because the new mission meant that four satellites and four payload and antenna systems would have to be designed, developed, integrated and launched in time," which was designated as mid-year 1967, Hammarstrom noted.⁵⁰ Unsure at first how their 10-minute entreaty went, Lorenzen and Mayo quickly found out: just as they were preparing to leave, their SAFSS liaison ushered them into the office of the Director of the NRO, Alexander Flax, interrupted a meeting that was in progress, and recommended that the director hear out Lorenzen that very minute.

By delaying the next ELINT launch by seven weeks, Lorenzen argued, NRL would be able to deliver a package of components that would enhance anti-ballistic missile signal detection at several Soviet sites, including the missile testing complex in Saryshagan. The plan entailed some upgrades at field stations, including the installation of powerful new computers in a foreign location that some insiders would defiantly object to. Flax gave him a tentative green light that very day.⁵¹

Now with wind at his back, Lorenzen mobilized Program C's Technical Operations Group to work out the logistics for acquiring and installing the computer equipment—designed specially by HRB Singer—that it would take to push the digital frontier forward in ways that would enable him to deliver what he promised to Flax. The computer was key, for example, to quickly vet the quality of raw data from the Poppy satellites; a lot of time and resources had been spent in the past on flawed tapes and data, up to half of which had proven unusable.⁵² And computer techniques would enable the quick identification and characterization of radar signals of interest, allowing for more leisurely analysis of the rest of the data.

In an unpublished memoir, Hammarstrom listed the engineering changes that his countermeasures colleagues and Wilhelm's Satellite Techniques Branch would have to pull off. Everything in the satellites seemed to be affected: the electrical systems and wiring, thermal control, magnetic and dynamic balances (due to new or redesigned components), antenna configuration, mechanical and launch systems. "The fact that Wilhelm's effort was successful gives direct proof that he probably is the world's top satellite designer," Hammarstrom stated.⁵³

Lorenzen received word on December 21, 1966, that the plan had been officially approved at the highest levels. On the same day, another ELINT asset, perhaps a Poppy satellite still in orbit, had acquired a crucial intercept, whose details remain classified. It was a shot in the arm for the cause of ELINT in general. Within months, Hellrich and Hammarstrom were able to mastermind and orchestrate—through the highest prioritization code (dubbed brickbat 01) in the Navy's supply system—an innovative, tailor-designed upgrade of the computers processing Poppy data.⁵⁴

Hellrich had been keeping up with media reports and professional literature about the advent of mini-computers and realized that these new types of computers, with suitable modifications, could boost the ability of suitably trained technicians at Poppy ground stations to quickly gather digitized data while also opening the way to, in the words of one declassified description of Hellrich's accomplishments, “near-real-time identification and geo-location of high priority intercepts.”⁵⁵

Hammarstrom added that a crucial computer feature the Poppy team needed for the ground stations—the ability to execute “real-time interrupts”—was rarely available in existing hardware. “In that era, most computers were designed to do ‘batch processing’ where the computer would start a job/batch, and continue until that job/batch finished,” Hammarstrom explained. Interrupting one computational job to make time for another was not possible. For upgrading Poppy's capabilities, machines capable of real-time interrupts were crucial, he continued, “so that data could be captured coming into the computer and not lost because the computer was doing another function.”⁵⁶

In quick succession, Hellrich determined the performance requirements of the mini-computers on the market, contracted with System Engineering Laboratory (a general-purpose computer maker in Ft. Lauderdale at the time) to supply the specified machines (SEL 810A),⁵⁷ and then oversaw the installation and integration, in May 1967, of the first one of these in a Poppy ground station in Europe. For the programming side, Hellrich turned to HRB Singer, as well as to a mathematician at Penn State, Dr. Robert E. Daniels. The Penn State scholar had written most of the Fortran code for the SEL 810A, but he was still working out the details for the Poppy version in May 1967 during his flight to the ground station where the computer was installed.⁵⁸



Data Cruncher. Key to increasing the useful information that could be eked from the ELINT data harvested from Poppy satellites was the acquisition of state-of-the-art computers, including the SEL 810A computer.

“This ushered in the first near-real-time digital processing of ELINT data with its accompanying orders of magnitude improvement in timeliness and accuracy—a true revolution in national reconnaissance collection, analysis and reporting,”⁵⁹ Potts wrote. An award citation Hellrich received many years after the Poppy program had

ended added that “this new technology allowed for the transmission and collection of compressed data, dramatically reducing the time required to process from weeks to minutes.” This was a time frame, the citation indicated, which enabled the Poppy system to become useful even to “the tactical user,” in addition to those looking at U.S. defense on a strategic level.⁶⁰

The development and implementation of these new computer systems turned Hellrich into a global traveler. Recalled Hellrich, “I essentially brought the computerized techniques to the processing of the data. I went around to the ground stations ... I can remember those first several years, right after I got my clearance ... I was overseas over six months out of the year.”⁶¹

In this same end-year time frame of 1966, top-level representatives in the ELINT community, including Lorenzen, began meeting to plan out the nation’s next-generation ELINT architecture, including the next blocks of Poppy satellites. For its part, NRL was proposing to move at an accelerated schedule compared to the past. “The committee recognized that Poppy had the potential to do a better job at location than anything else flying, and that Lorenzen was keen on identifying new capabilities that might be incorporated with Poppy 7—still in the conceptual stage,” according to Potts.⁶² NSA also expressed plans to add 100 people to its K-4/SP office in which the ELINT system processing and analysis was done.

These were encouraging developments for the NRL ELINT masters. But ongoing analyses of the types of radar intercepts the U.S. would like to make on a regular basis, in addition to ELINT assets on various drawing boards, were adding uncertainty to the picture. Even though Poppy had a track record and was almost certain to offer ever better ELINT capabilities, it was no longer clear it would be better than new systems others in the ELINT community were proposing.⁶³

Specifics of maneuverings and decision making during the rest of the 1960s regarding ELINT for tracking ABM/AES systems remain mostly secret, though Poppy 5 already was set for a launch in 1967 and Poppy 6 and 7 had entered an accelerated planning phase.⁶⁴ With its usual bravado, the NRL ELINT satellite team was at full throttle, a pace that was made a little easier with an influx of money for the ABM/AES problem from the Air Force Space Systems Division.

The sense of urgency due to the ABM/AES problem quickened all aspects of the Poppy program. George Price, the son of Charlie Price, whose work had centered on the collection and interrogation huts, began working for NRL and applied his electrical engineering expertise to the classified program. The second-generation Price worked closely with HRB Singer partners to work up the engineering models of solid-state receiver electronics designed and built at NRL into production models. HRB also worked Wald’s design of an Analog to Digital Data System (A/DDS) into production models. Others in Mayo’s group were working on data-recording systems.

Amidst all this work on the data handling side, no one was forgetting about the satellites. Poppy 5’s quartet (two sets of two) made it into orbit atop a Thor Agena D

that roared into orbit from the Vandenberg launchpad on May 31, 1967. This time, in a role that presaged his future, Wilhelm was chief designer of the 12-sided satellites, which were 27 inches across, lined with solar arrays, and weighed between 162 and 222 pounds.⁶⁵ Bob Beal, the head mechanical engineer in the program, and extendable boom expert Bill Collins, among others, had taken on the stabilization task by developing an experimental system that could work in three axes, not just the one pointing toward Earth as previous gravity-gradient systems had done.

The results were good enough that the follow-on satellite blocks, beginning with Poppy 6, would include a boom with a damper mechanism that could calm pitch and roll motions, and an innovative motor-driven flywheel to control yaw. For the latter, electrical engineer George Flach of the Satellite Techniques Branch drew on lessons learned from a yaw-control system designed for NASA's Nimbus meteorological satellites.

Once Poppy 5 became operational, its data provided guidance for changes to the design and capabilities of Poppy 6. Both the sheer amount of data this block of Poppy satellites brought in day in and day out, and the spectral range of its RF coverage, was astonishing to the ELINT community.⁶⁶ "The fact that Poppy produced valuable intelligence so quickly after launch was particularly important and helped continue support from [NRO Director] Flax," Hammarstrom recalled.⁶⁷

The abundance of data posed the danger of becoming a liability, again. "Turn down the gain," the phrase from NSA analysts that had evoked laughter and even pride in the early days of GRAB, now indicated a more serious issue as NSA was unable to keep up with the data flow despite its 24/7 operation. Data from only about half of the satellite passes over the Soviet Union were getting processed. The backlog, particularly of tapes with analog data that needed to be digitized and then processed, sometimes was shortened by a quick and dirty technique: degaussing entire blocks of tape, that is, wiping the tapes clean of the data that had been collected, rather than leaving the tapes in a processing and analysis queue.⁶⁸

In his never-ending quest to keep top national leadership in favor of Poppy by showing them firsthand how it worked and what it could do, Lorenzen brought Dr. Louis Tordella, Deputy Director of the National Security Agency, to a primary ground station where 116 personnel conducted collection and analysis operations on both conventionally acquired ELINT and that obtained via Poppy, which was sometimes referred to by another code name: Siss Zulu.

In the operations room, Tordella could see little red lights from the "cherry picker," an electronic box that could flag what presumably were signals of interest.⁶⁹ He could see how backup systems would kick in when a digital recorder went on the blink until engineers could isolate and replace, say, its faulty diodes. He could see analysts pouring over stacks of paper from the line printer and annotating them with computations and arrows connecting signals that seemed to suggest something more together than either signal did in isolation.

The meeting had the hoped-for effect on Tordella. But the love for Poppy was waning in other sectors of the defense and intelligence communities, which were questioning just how all of this time-consuming and tedious effort had been contributing to the discovery and characterization of radars associated with the primary strategic concern at the time—Soviet ABM systems.⁷⁰ A hint of how labor-intensive it was to eke payoff from Poppy data was that it took 700 work-hours of signal isolation, orbital calculation, and data analysis to characterize one “signal of interest,” which had been retrieved at a ground station that still had relatively rudimentary data analysis and processing equipment. It would take more upgrades and lot of money to address that limitation.⁷¹

Just before that reality check, yet another reorganization took place at the top of the U.S. intelligence infrastructure with the creation within the U.S. Intelligence Board of a SIGINT Overhead Reconnaissance Subcommittee (SORS). Once again, Lorenzen and Poppy’s champions at NRL and NSA had to bring up to speed new players with authority over Poppy. They held a briefing at NRL for the new SORS on December 13, 1967, and did a repeat for the top NRO office associated with Program C.⁷² Had these briefings taken place just a little later, the Poppy champions would have been able to boast of their project’s coup of recording signals for the first time from a Soviet ABM radar system that was at the top of the nation’s ELINT priorities.⁷³

As the Soviet Union was designing an ever-evolving set of radar systems in its land-based military operations during the 1960s, it also was building a fleet of frigates, destroyers, nuclear submarines with ballistic missiles, and other naval instruments of war. A mandate by the national intelligence community was to identify and track technology changes occurring in the Soviet Union, including the migration of existing or new radar and other RF-based systems to the sea. As such, the national mission for ELINT, including the Poppy program, began to include reconnaissance of sea-based systems.

In 1966, the Navy’s bureaus, including the Bureau of Weapons that had been the primary financial overseer of NRL’s Poppy program, became part of a large-scale reorganization with the bureau system being restructured into commands. Naval Air Systems Command subsumed exploratory space technology work, mainly at NRL, in a space systems division. Amidst this large structural change, the Deputy Chief of Naval Operations, Vice Admiral Thomas Connolly, called for a review of the Navy’s overall space activities. Out of this would come some middle-burner tasking for overseas Siss Zulu ground station sites to begin exploring their abilities to use Poppy data as a window on emitters on Soviet ships. This was to be done so long as it did not interfere with the primary national priority that focused on strategic radars, such as ones associated with ABM systems.⁷⁴

In September 1967, a two-week-long review of the Navy’s space programs and plans unfolded at NRL, hosted by Captain Jim Matheson, who had taken over as NRL’s Commanding Officer just a few days before the launch of Poppy 5. Among the topics were navigation, ocean surveillance of both acoustic and overhead sorts, meteorology

and oceanographic applications, all sensor-based military reconnaissance, communications, and fleet security. During the review, Bill Faust, superintendent of NRL's Space Applications Division, represented NRL and briefed the gathering about NRL's multifaceted space portfolio, including (1) space technology experiments, (2) space-based science work such as the SOLRAD series to measure solar radiation, (3) calibration of the NAVSPASUR system for keeping track of anything flying in space over the United States, (4) a new experimental navigation system known as Timation (the name derives from "time transfer and navigation," which would become the basis for the Global Positioning System), and (5) high frequency propagation studies to calibrate HF/DF technologies.⁷⁵

The unsurprising conclusion of the review was that space was destined to become a hugely important venue for the Navy. But this meant the Navy would have to work things out with the Air Force, which since 1961 had been assigned, according to an official directive at that time by Secretary of Defense McNamara, the responsibility for the development and acquisition of the nation's overall military space program, which included the Navy's component.⁷⁶ Only mentioned in the most widely distributed form of the official report that came out of the program review was the task of space-based ocean surveillance. The report noted, for example, a doubling of Soviet naval presence in the Mediterranean in 1967.⁷⁷

There also was a highly classified portion of the report by which Rear Admiral William Leonard, Director of the Joint Chiefs of Staff's Office of Defense Research and Engineering (DR&E), learned about the Poppy program. A former commander of a carrier division, Leonard was a quick convert to the potential of Poppy satellites for tracking Soviet naval vessels. Key to his optimism in that regard was a briefing he received about an NRL navigation satellite, Timation 1 (see next chapter), which was launched in 1967 and that, in Hammarstrom's words, "had demonstrated its potential to provide locations on moving platforms, boats and planes."⁷⁸ Leonard subsequently relayed the following entreaty to Chief of Naval Operations (CNO) Thomas Moorer: "Request the conduct of tests by the NRO to evaluate satellite use for passive detection, classification, and localization of ships at sea."⁷⁹

Soon after, wartime events in Vietnam and the Pacific Rim reinforced the recommendation. On January 23, 1968, for one, North Korean naval forces attacked and captured the SIGINT ship USS *Pueblo*. Members of the captured crew, including some who previously had worked at Poppy field stations, were brutalized.⁸⁰ These and other less publicly known losses during in-air and on-sea SIGINT operations highlighted the sense of urgency on the part of the intelligence community to rely more heavily on less risky space platforms for collecting SIGINT, of which ELINT was a pivotal component.⁸¹

In the same time period, tidal shifts yet again were occurring in the top echelons of military and intelligence decision makers. Secretary of Defense McNamara, for one, resigned at the end of February 1968 even as the SIGINT community was amidst

a review that he had commissioned. It was the sort of managerial and administrative shift that required the Navy's champions of NRL's satellite programs to make sure they communicated their support up the authority chain as well as down to the engineering trenches, such as in NRL's Countermeasures and Satellite Techniques Branches, where the new national technical means of intelligence gathering were conceived of and realized.

Toward that end, Lorenzen met at the Pentagon on April 3 with CNO Moorer, a former commander of the Seventh Fleet.⁸² The discussion focused on the topic of geolocation. Could satellite-based ELINT locate radars on ships the way it did land-based radar systems embedded in concrete, the CNO asked? He pointed out to Mayo and Lorenzen that the White House was concerned about the number of days it took to receive usable photoreconnaissance. Could ELINT provide the information on ship location and movement faster by tapping into electronic emissions?⁸³

The NRL duo was unable to lay out right then for the CNO all that it would take, but the prospect of shifting at least some of Poppy's attention toward ocean surveillance had instantly become a high priority. At the end of the meeting, Moorer called for a monthly briefing memo on Poppy, quarterly progress reports, and for a personal visit to NRL so that he could see the Poppy satellite team in action for himself.

The Moorer meeting revved up momentum on the Poppy program. As a start, NRL and NSA collaborated on examining signals of interest (SOIs) that Poppy recently had intercepted from shipborne emitters and conducted an engineering evaluation of what it would take to leverage those intercepts into an ability to locate ships at sea. The potential here was for entirely new and more comprehensive awareness of naval activity in the maritime domain.⁸⁴

Mayo knew the task would require a full buy-in from the crews at the ground stations, and his frequent warm and responsive attention over the years to the needs of these crews would pave the way for that. His visits to the ground stations provided for the crews a sense of linkage all the way to the CNO's office or the Director of the NSA. At the same time, Mayo made it clear he was there to take care of them. "Mr. Mayo would listen and act on their needs for equipment or technical information or logistics support or even a water cooler," noted Potts.⁸⁵

On a trip to one ground station, Mayo learned that the crew there had identified an SOI from a Soviet ship 11 days after the Moorer briefing. More than that, a petty officer at the site had used the SEL 810A—the computer that Hellrich had procured for upgrading data analysis at field stations—to eke out a specific ship location from the signal data. It was a proof of principle of more rapid identification of SOIs, but the engineering evaluation of using Poppy for full-blown ocean surveillance remained inconclusive amidst more pressing electronic countermeasures (ECM) demands on Lorenzen and his staff that came with the prosecution of the war in Vietnam. NRL's Electronic Warfare Division, for example, had been fitting the refurbished USS *New Jersey* with "repeater jammers" and other ECM equipment to thwart attacks

by guided missiles and even suicide missions by North Vietnamese in fast attack vessels.⁸⁶

On July 29, 1968, Lorenzen hosted the Assistant Secretary of the Navy, Dr. Robert Frosch, at NRL for a briefing on the lab's major technology trajectories, among them, moon relay communications, high frequency direction finding, tactical electronic countermeasures, and, of course, satellite projects. The briefing included a 30-minute segment inside a secure briefing vault so that Frosch could be brought up to speed on the classified satellite programs. There, Mayo described the first localization successes by Poppy satellites of shipborne emitters. Also at the meeting, Wilhelm briefed Frosch and Dr. Alan Berman, who in 1967 had assumed the role of NRL's Director of Research, on specific technical developments, among them more capable onboard memory components and improvements in stabilization, attitude sensing, and thrusting, all of which would improve the localization ability of NRL's follow-on ELINT satellites.⁸⁷

As the summer progressed, tensions rose as the Soviet Union's Red Army was conducting maneuvers along its borders.⁸⁸ At the same time, the Soviets were adding modernized vessels to their naval fleet. With new software, experience, and training, it was becoming possible to locate ships at sea by way of electronic intercepts in hours rather than days, though there still was a noticeable trade-off between speed and the precision of the localization. Use of the NAVSPASUR system to trace out the trajectory, or ephemeris, of the satellites at the time a Poppy intercept of radar signals was made was helping the cause, but that process could take days.

Even in the absence of an up-chain buy-in to ocean surveillance, Captain Lloyd W. Moffett, who reported for duty in late 1967 to the Naval Intelligence Command, became a major and vocal champion of developing naval space assets for gathering, interpreting, processing, and distributing tactically relevant information as efficiently, swiftly, and actionably as possible.⁸⁹ There was work to be done along these lines; still in the Poppy data-handling protocol at the time, for one, were sneaker-clad seamen running message pouches between buildings. It would take four years before Poppy processing would become automated enough to routinely beat out procedures that included humans in the loop.⁹⁰

On August 16, 1968, a high-level analysis of the national ELINT program, known as the Eaton Report, was delivered to Richard Helms, the new Director of Central Intelligence. The report noted that the national-mission emphasis on strategic anti-ballistic missile and anti-earth-satellite (ABM/AES) systems left tactical electronic warfare for the armed services at a dangerously low capability level. At the same time, Secretary of Defense Paul Nitze had raised the profile of the NRO, including NRL's ELINT program within it, with the secretaries of the military services under his wing. The Eaton Report—in addition to briefings by Lorenzen and Moffett to the Secretary of the Navy (Paul Ignatius) and the Vice CNO (Bernard Carey)—rekindled interest of top Navy brass to bolster its ocean surveillance capabilities. Rear Admiral

Frederick J. Harlfinger, II, the new Assistant CNO and Moffett's replacement as Poppy program head, had been a submariner and had extensive experience in the intelligence channels. He was well aware of Poppy's ELINT roles.⁹¹

Within the context of top-level decision making in the Navy, the hunger for tactical applications of Poppy was intensifying. And on September 22, 1968, Poppy made an unprecedented intercept that demonstrated a boost in the system's ability to locate ships as sea.⁹²

The growing ability of the Poppy system to detect, classify, and geolocate radar signals, which was the key for the system for tactical purposes, was coming to the attention of top Navy leadership in a series of briefings. "For these discussions, a simple world map, a commonplace feature on walls of executive offices of that era, was the only prop, and there was no script," Potts wrote. "Tracks were drawn with a finger or pointer, ships and radars and parameters were identified verbally, missile and ABM sites and test centers were pointed to and their associated systems named." The upshot was that Captain Ralph Cook, commander of the Naval Security Group, which oversaw the Navy's use of ELINT, asked at the end of 1968 for "a system concept to exploit the system for Navy support."⁹³ This was an enormous shift for NRL's ELINT satellite cadre in that it expanded its thinking from strategic intelligence gathering, which had time frames more in terms of weeks and months, to tactical intelligence gathering (a type of SMO, or Support for Military Operations)⁹⁴ for which daily and hourly updates are what field commanders need.

When potential new capabilities get boiled down from countless meetings and briefing to three-page memoranda for top-echelon decision makers, as was the case in late November 1968, things are getting serious. Due to the importance of accurate ephemeris data for the precise reporting of at-sea ship locations, the NAVSPASUR system, the nation's premier system for tracking satellites, became an even more important part of the overall Poppy program. This, in turn, upped the prioritization of digitizing facilities.⁹⁵ And this, in turn, trickled down to Charlie Price, the NRL facilities go-to guy, who needed to take care of a thousand details, including such minutiae as improving the air conditioning at the collection sites to prevent stoppages due to overheating recorders and other equipment. For his part, Mayo was authorized to hire more employees for his overall responsibilities in payload and "ground segment" development.⁹⁶

In lieu of enough NRL staff proficient in all aspects of the expanding program, Mayo and other Poppy principals relied heavily on the contractor HRB Singer, based in State College, Pennsylvania, to handle hardware and software issues and even R&D for ground systems and for overseas assignments. The growing team of mathematicians, algorithm developers, and program developers got busy nicking off the hours, minutes, and seconds it took to go from the detection of a signal by a Poppy payload to a localization of that emission⁹⁷ on the ground or sea.⁹⁸

Discussion about the great potential of ocean surveillance for national security and military tactical applications was breaking out into civilian sectors too, includ-

ing among them the President's Science Advisory Committee. This provided another forum for assessing and perhaps pushing for what some circles called the "Program 749" concept, which is to say at-sea localization by way of SIGINT (including ELINT). "Radar would detect iron on water," Potts wrote. "ELINT would determine whether it was friend or foe." The technology was in hand to put such a system in place. Tougher was getting the money to make it so.⁹⁹

During the second week of 1969, Poppy veteran Captain Lloyd Moffett gave CNO Moorer a full briefing about how the Navy's ELINT capabilities could be used against the growing Soviet naval threat. Rear Admiral Harlfinger, the Assistant CNO charged with liaising for the CNO on naval space projects, assembled an Executive Tactical Operations Group (Ex-TOG) to drill into the questions of just how Poppy could play in the growing ocean surveillance task and how to make future systems as capable along these lines as possible.¹⁰⁰

Interest at the top of the Navy now could hardly have been higher. Lorenzen and Mayo, the Ex-TOG's only civilian members, joined two Captains and seven Rear Admirals. The elements were in place for taking Poppy into a new era of tactical ocean surveillance. But that would only happen if Poppy's designers and champions could convince the U.S. Intelligence Board (USIB) that ocean surveillance, which seemed like it was within a tactical context, was in fact at least as valuable as a strategic ELINT capability that focused on Soviet radars for stopping land- and submarine-launched nuclear missiles and strategic bombers.¹⁰¹

In January 1969, Richard M. Nixon had assumed the Presidency of the United States and expressed his intent on ending the Vietnam War. The war had squeezed funding for many programs in the Department of Defense and so budget offices, including NRO's, were looking for places to cut; Program C was on the table. There was some concern by critical insiders that Program C existed largely to appease the Navy and so might not be justifiable from a budgetary perspective, especially when the Air Force had new ELINT capabilities in the pipeline that could overlap with Navy assets.¹⁰²

The budget axe would have fallen on Poppy had the National Reconnaissance Program's (NRP) budget officer not been given the opportunity to witness firsthand, in Potts' words, "a live pass as sailors commanded the satellites, tracked downlink signals, collected data, and made log entries of SOIs detected on-line." The officer "then saw a watch analyst dissect a technical SOI in the off line analysis room, while the analog chief, Ronnie Brooks,¹⁰³ explained the [REDACTED] patterns on dual beam oscilloscopes, and functions of the test oscillators, audio spectrum analyzer, oscillograph, brush recorder, and special stop watches. In the computer room he witnessed successful post-pass digital process for [REDACTED] and listened, above the line printer clatter, to explanations of each step by the leading digital analyst, Petty Officer James M. Arnold." It didn't stop there. Maintenance, logistics, equipment upgrades, and all questions were answered. For the time being anyway, NRL's Poppy program was deemed as nonexpendable.¹⁰⁴

March 19, 1969, was a big day for Program C and therefore for NRL's space technologists. At CIA headquarters in Langley, Virginia, Captain Moffett (head of Naval Intelligence Command), Lieutenant Commander Ron Potts (NSA and future historian of Program C), and NRL's Mayo and Hammarstrom, briefed the SIGINT Overhead Reconnaissance Subcommittee (SORS) of the USIB on the Navy part (Program C) of the NRP. Part of the challenge for the Navy program was that its claim that it would monitor Soviet naval activities, even on the scale of single ships, was ambitious. Moreover, its actual value depended on technical details, among them the speed of reporting and the location accuracy the Poppy data would be able to deliver. It was clear, for one thing, that existing data flow and processing abilities for Program C would not be sufficient for the timely delivery of global-scale ocean surveillance data. The Poppy team would have to nail those and other specifics down if they were ever going to get a chance to pitch the program's value to the full USIB.

It was a time of peril for the NRL satellite builders. To SORS members, the proposal for ocean surveillance appeared to be a Navy-specific value that was diverting Program C from its national tasking. Yet the Navy wanted the national intelligence infrastructure, most notably USIB, to view ocean surveillance as a nationally valuable means.

In his weekly meeting with SORS, Captain Moffett could see that this view was going to be a tough sell to the subcommittee and that more solid documentation could help the cause.¹⁰⁵ With input from Mayo regarding technical feasibility and costs, ELINT representatives from NSA and the Naval Security Group prepared a detailed report titled "The Development of an Ocean Surveillance Capability."¹⁰⁶

Even before the report was in its final form, the Poppy team's argument to think of ocean surveillance as a national capability got a helpful nod from a separate NSA progress report regarding the ELINT program's primary and original mission to keep track of strategic Soviet radars: "A great deal of the success achieved against the Soviet ABM effort can be attributed to the collection and processing efforts of Poppy. The success of the Poppy vehicles in detecting those signals can in turn be directly attributed to the [REDACTED] capability designed into the system from its inception and the demonstrated capability that [REDACTED] intercept does give a high probably of intercept of new emitters in the R&D testing phase. Stated in the most direct terms, all of the ABM signals detected by SIGINT satellites were detected first by Poppy."¹⁰⁷ This placed Poppy in a favorable light for the proposed new mission of ocean surveillance.

On April 8, 1969, NRL rolled out the red carpet for a blue ribbon gathering of Rear Admirals and other Navy leaders to solidify confidence and Navy support of the Poppy program. Civilian research director, Dr. Alan Berman, welcomed the distinguished group to the lab; Mayo, Wilhelm, and a few others orchestrated the tour of hardware. On display were the four fully assembled satellites that constituted Poppy 6, which would be the second-to-last block of the program, as well as five other NRL

satellites slated for a record nine-payload launch in September. The finale of the tour was a real-time relay of signals from Poppy satellites overhead to remind those on the tour of the electronic intelligence that the program was detecting and downlinking several times every day to multiple collection sites.¹⁰⁸

The next day, Wilhelm gave Colonel Lew Allen and other influential program managers from the NRO a VIP tour of the satellite technology facilities and captured Allen's attention with some of the satellites' technical innovations, such as the gravity stabilization technique. Later in the day, Mayo briefed eight members of the NRO Programs A (Air Force) and B (CIA) on Poppy's ELINT results and ability to track ships. For his part, Lorenzen was in Europe at the time bringing major commands there up to speed on Poppy capabilities.¹⁰⁹

April brought yet more briefings and more opportunities for visitors with top security clearances to hear, in real time, "the voice of Poppy," that is, the chirps of intercepted radar pulses. And it brought the Navy's next big play in its quest to leverage the work NRL's satellite team had been doing for the defense tasks of the coming years: the Commander of the Naval Security Group (CNSG), Rear Admiral Ralph Cook, recommended an entirely new satellite system, based on Poppy technology, dedicated to the new oceanic task. More briefings, this time for the likes of the Under Secretary of the Navy (John Warner) and the Assistant Secretary of the Navy for R&D (Robert Frosch). And more live demos. Momentum within the Navy was swinging in the direction of getting an ocean surveillance satellite system going, even if that meant tasking National Reconnaissance Program assets such as Poppy to do so.¹¹⁰

In the summer of 1969, in a sign that the Navy was slowly winning the hearts and minds of the nation's intelligence leadership, the Poppy program received authorization to experimentally deploy ELINT assets for a two-week period to intercept Soviet seaborne signals and relay them to the Commander-in-Chief of the European Command (CINCEUR, General Andrew Goodpaster). It was the first time that SORS, and therefore USIB, has issued a one-off task of ocean surveillance of Soviet ships.¹¹¹

In September 1969, five months after CNSG Cook had submitted the proposal for using Poppy technology to develop a tactical ocean surveillance system, he received a letter from Assistant CNO Harlfinger directing him and thereby NRL to move forward with the ocean surveillance task. Everyone in the program knew that at the heart of any progress was the handling and processing of data, and the continued migration from analog to digital formats throughout the data flow. And the NRL team was delivering. An example of the latest and greatest components entering the system was a 1.5-megabyte "moveable head disk" the size of a washing machine from which signal analysis programs and other software tools could be accessed more efficiently. With this constantly upgrading system, Poppy had been acquiring more emitter reports from Soviet ships, bolstering Cook's and others' confidence that the system indeed could be used for ocean surveillance.¹¹²

On September 30, 1969, with a Thor Agena D booster, the Poppy 6 satellite cluster was placed into orbit from Vandenberg Air Force Base. Each member satellite included three-axis stabilization equipment and microthrusters for fine attitude and station-keeping adjustments. The checkout phase in the early orbits indicated all was well, but there were challenges too: in early October, the final stage of the Agena D booster apparently exploded in its orbit, scattering space debris that could endanger the Poppy satellites; and there were new and more powerful computers at NSA into which the data flow needed to be assimilated.¹¹³

In his relentless quest to keep NRL in the forefront of national ELINT, Lorenzen made sure to meet with the new NSA director, Vice Admiral Noel Gayler, to register concern about how Poppy data tapes were being handled after NSA personnel acquired them and about the difficulties the NRL team was having in procuring copies of the tapes and other data products that would help guide their development of better ocean-surveillance capabilities. What was needed, insiders agreed, was a more integrated process that could reduce processing redundancy between field and central sites. Toward that end, Fred Hellrich became NRL's point man on the first joint task with NSA to focus on issues of processing and automation in the data system.

Meanwhile, other enormous issues for NRL's satellite technology group were on the horizon, mostly notably the Air Force's decision to phase out the Thor Agena D booster to make way for the more powerful, next-generation Titan III, which would become NRO's workhorse ferry to orbit.¹¹⁴ That booster shift was serious news to the NRL team, especially to Pete Wilhelm. He knew that it meant a major redesign of the satellites then in the planning and building phases.¹¹⁵

In December 1969, the authority chain for the emerging ocean surveillance system was falling into place. Commanders and intelligence leaders with U.S. Navy operations in Europe were briefed on the new Poppy capabilities and tasks. The CNO and other officials were signing and endorsing a "final requirements letter," which was part of the officialdom required before Poppy would become a bona fide ocean surveillance system that the U.S. Navy could put to use for tactical purposes. Poppy 6, meanwhile, was delivering novel intercepts of Soviet seaborne emitters.¹¹⁶

Amidst all of the technical, institutional, bureaucratic, and other obstacles that had made a pathway to ocean surveillance of Soviet warships so difficult to get into place, the engineers, technicians, and mathematicians who knew how to create and assemble the pieces had been busy doing so. By early 1970, much of the capability was in hand and Lorenzen convened a meeting with some three dozen ELINT managers associated with NRL, NSG, and NSA to hammer out protocols for exchanging "information on technology, techniques and high-priority targets." At this meeting, Mayo, Wilhelm, Rose, and Hammarstrom spoke about, respectively, the program history, spacecraft hardware and satellite techniques, ELINT payloads, and data processing.¹¹⁷

The oversight seemed endless to the NRLers. On February 11, 1970, an ELINT Research, Development, Technology and Engineering coordinating group with

multi-agency representation reviewed NRLs ELINT capabilities. Among those present was Edwin Speakman of the Army Security Group, the Army's counterpart to the NSG. Twenty years earlier, he had been head of NRL's countermeasures group (in NRL's Radio Division) and so was Lorenzen's supervisor at that time. "It had been a reunion of old friends and pioneers in ELINT," Potts wrote.¹¹⁸

Soon afterward, the SIGINT Overhead Reconnaissance Subcommittee of the USIB approved a proposal for the execution of quick tasking of requests for Poppy satellites and other overhead assets submitted by top Navy managers in the European and Atlantic fleets. The goal was to provide Navy commanders with timely ELINT data on Soviet warships in their jurisdictions. Interest was rebuilding within top-echelon military and intelligence offices, especially the Naval Security Group, for ocean surveillance. Part of the thinking called for additional Poppy receiving stations devoted to the new task so that Poppy's traditional national task, which focused on Soviet ABM/AES threats, would remain unhindered.

Then came what seemed to be a roadblock. When USIB issued its new ELINT requirements document in May 1970, there was no sign of ocean surveillance in its 32 pages.¹¹⁹ The report did stress, among other things, the continued need for Poppy to harvest scientific and technical intelligence measurements and to conduct its traditional role of eavesdropping on ABM radar systems.

At the same time, there were others in high places who wanted to see the Poppy system exploited for ocean surveillance. Among them was the Secretary of the Navy, John Chafee, who let the Deputy Secretary of Defense, David Packard (who had influence in the NRO and could get the President's ear), know about this vision in a memorandum, dated July 11, 1970, with the subject line: "Use of POPPY Elint System for Ocean Surveillance." Given the growing threat from Soviet naval vessels, Chafee wrote, "the Navy must be able to locate, identify and track all Soviet naval units, especially all missile delivery platforms and threats to our seaborne strategic deterrent forces ... The threat posed by the Soviet Navy is of such significance today that surveillance of these type of platforms must now be recognized as a national requirement, and the use of national overhead reconnaissance assets should be utilized, where capable, to respond to this requirement."¹²⁰ In an administrative move that would enable the Navy to get "more aggressive in space," Hammarstrom noted, Packard managed in 1970 to rescind the 1961 policy that designated the Air Force as the service in charge of military space development and systems acquisition.¹²¹

In this same time frame, Hammarstrom noted, Captain Moffett developed a set of requirements for modernizing the data flow that became known by insiders as the "Moffett Index." "They were defined in a complex set of performance, timeliness, and dissemination" metrics, Hammarstrom recounted. "The matrix not only included satellite challenges, but also ground station, processing and dissemination challenges."¹²² It was a set of specific, quantified guidelines that mobilized all the lead players to redefine and redesign what would be the last set of Poppy payloads, though the in-

novations that emerged from this work would find extensive applications in follow-on payloads and systems. Among these was the Multiple Satellite Dispenser (MSD), designed under the leadership of Wilhelm, which could ferry satellites attached to it to individual orbital injection locations, and ground station redesigns orchestrated by Hellrich that featured next-generation computers along with software customized by in-house experts.¹²³

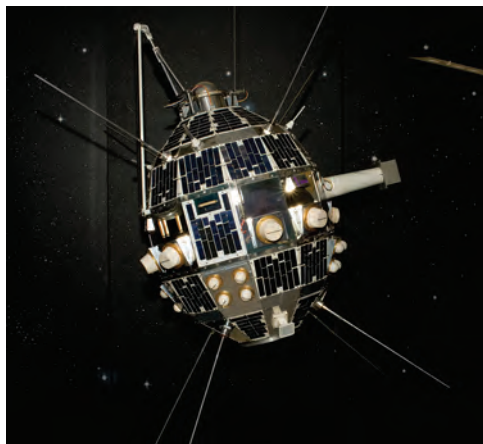
Greatly boosting the argument to move forward in the way Moffett envisioned was the Poppy team's ability to augment the system with additional analysis centers dedicated for ocean surveillance co-located with existing ground sites. That way, the overall program could conduct the ocean surveillance as tactical support for operational commanders without interfering with the original top-priority task of monitoring Soviet ABM systems. Chafee's memorandum included specifics about personnel, costs, and other logistical details without which such proposals normally would die on the vine. The Naval Security Group, working with NRL's Charlie Price and others, would be responsible for getting the new receiving facilities on line and for training personnel to run them. NRL would be in charge of filling the facilities with analysis equipment and the software to run it.¹²⁴

In this 1970 time frame, top-tier decision makers in intelligence and defense circles began embracing ocean surveillance as a national intelligence objective just as monitoring Soviet ABM radars always had been. On September 11, Deputy Secretary of Defense Packard approved a Poppy augmentation, mostly by way of computer and analysis upgrades, for achieving the required new ocean surveillance capability. It was a welcome vote of confidence for the Poppy program.¹²⁵

The Director of NRO at the time, Dr. John L. McLucas, summed up the Poppy augmentation decisions in an October 7, 1970, memorandum for the Secretary of the Navy. The bottom line was that ocean surveillance of Soviet ships was imperative and that modest interim steps, in the form of the installation of new computers and a new analysis facility, should begin promptly. The memorandum reiterated NSA's role as "the agency responsible for processing and analysis of overhead ELINT data" and gave NRL (within the auspices of NRO's Program C) the tasks of developing, acquiring, and installing the equipment required to make the entire system ready for ocean surveillance.¹²⁶ Not even 10 days after the memorandum was issued, the first Poppy augmentation meeting was held at the Pentagon. Helping out was an old hand, Ed Dix, a former head of the Satellite Techniques Branch at NRL who had moved to COMSAT, but now was back in the national ELINT picture as a consultant for Program C's leadership. A renewed sense of cooperation and an arrival at new agreements on such key issues as computer configurations appeared to be in hand ... sort of.¹²⁷

The buildup for Poppy 7, most notably construction of the satellites at NRL, was running into cost overruns. Wilhelm had to make a request to NRO for more funds. Ironically, the success of the NASA Apollo moon missions, which increased demand for space hardware, had run up prices on many key satellite components. Also adding

to Wilhelm's concerns was a malfunction, a stuck relay switch, earlier in the Poppy program that resulted in an expensive failure analysis by his Satellite Techniques Branch, the addition of costly "precautionary redundancies" to avoid a repeat of the failure, and a chronic anxiety that the same failure nonetheless could happen again. Adding yet more costs were the technology additions it would take to meet the new ocean surveillance task.¹²⁸



Poppy 7. Hanging in the exhibits room in NRL's Bldg. 222, this model of Poppy 7 depicts the final spacecraft in the successor program to the U.S.'s first ELINT satellite program, GRAB (Galactic Radiation and Background). Conceived of and developed by NRL, Poppy expanded into a multi-agency system in 1962 with the establishment of the National Reconnaissance Office (NRO) just before the first Poppy payload was launched. Poppy spacecraft detected both land-based and later sea-based radar emitters. The Poppy program was partially declassified in 2005. (NRL photo WFD_0932.jpg)

As always, extra funding requests like these were harrowing because higher level decision makers at, say, the NRO, were less vested in any particular system, such as Poppy, than they were in the overall intelligence capability. If an organization other than NRL could fulfill the overhead ocean surveillance requirement in ways that decision makers at NRO, USIB, and other top-level bodies deemed better or more economical, then that suitor could get the contract.

As the NRO examined more deeply which of the "national technical means" at hand might help the cause of tracking Soviet naval vessels, the Navy was rearranging its top managerial tiers associated with overhead intelligence tools. Taking the helm of the Poppy program for the Navy was Captain Robert (Bob) Geiger, a former Navy pilot with a master's degree in aeronautical engineering from MIT. Geiger previously had worked in the Air Force's Office of Space Systems, the name for an NRO office that oversaw the nation's overhead intelligence assets. CNO Admiral Elmo R. Zumwalt, Jr., saw in Geiger just what the Navy space program needed and took steps to create a new managerial infrastructure within the Naval Material Command (NAVMAT).¹²⁹

This should have been good news for the satellite team at NRL as they continued preparing for the launch of Poppy 7, scheduled for late 1971. But the cost overruns that Wilhelm had identified and for which the lab requested additional funding had earned the entire Poppy program a probationary status. A tough start for Geiger, to be sure. One cost saving move was to cut an R&D payload that the NRL team had proposed for the launch. As part of the probation conditions, Captain Geiger was tasked

with sending detailed status reports to the Deputy Director of NRO on a monthly basis. The heat went to the top at NRL—to the Commanding Officer Captain Earl Sapp and the civilian Director of Research Alan Berman. That catalyzed an internal version of the oversight and accountability reporting that the NRO was requesting of NRL's Program C team. It was bureaucratic detail on top of bureaucratic detail.¹³⁰

NRL's secret satellite program, now 13 years old since its 1958 conception by Mayo in a Howard Johnson's restaurant, had become larger than the rest of the lab's electronic warfare effort. To accommodate that fact, Berman enacted major organizational changes at the lab. He collected those non-space branches working on electronic warfare problems into a new Tactical Electronic Warfare (TEW) Division. The new division's focus was on the defense of aircraft, surface ships, and submarines. Lyn Cosby, long the lab's primary engineer on electronic countermeasures equipment for aircraft, took over as head of TEW. Berman also christened a new Space Systems Division, which subsumed most of the lab's space technology programs, among them data systems and navigation systems. Within this division was Wilhelm's Satellite Techniques Branch, which supported all the other Division branches. Heading up this new division was Howard Lorenzen, who moved from his former job as head of the Electronic Warfare Division (now TEW).¹³¹ Adding to the shuffle was a new Communications Science Division, with two of its branches run by GRAB and Poppy veterans Bob Misner and Mack Sheets. Bruce Wald, who had been playing key roles in the digitization, computerization, and automation of the ELINT systems, would become this division's superintendent in 1972.

Amidst all of this organizational and managerial change, Poppy satellites were orbiting the planet and listening in on the electromagnetic cacophony over the denied areas of the Soviet Union, as well as over the world's oceans where Soviet warships cruised. A testament to the program's technical successes was that the NRO's Program B, which centered on photoreconnaissance, was tasked, at least on a few occasions, to confirm the interpretation of ELINT signals of interest, rather than the other way around.¹³²

They did not know it then, but at the time, the staff in NRL's Satellite Techniques Branch was building what became the last block of Poppy satellites, Poppy 7. The project looked like it would become unavoidably too expensive for NRL to continue when the Air Force decided to switch to a Martin Marietta Titan III booster, which generated 10G's of thrust rather than the previous booster's 4.5G's. This uptick in mechanical force required sturdier satellites, which entailed a lot of expensive reengineering. There was no way around that, but to the financial analysts in the loop, the Poppy satellites suddenly looked way more expensive than they had been.¹³³

The NRL team was working at top speed to get Poppy 7 ready for a December launch and for its new ocean surveillance roles. Hammarstrom and Hellrich were respectively working on the software and hardware side of the automated data processing system. George Price was the lead on new data extraction equipment. After

components were tested and validated, the NRL Poppy team integrated them into working subsystems, which they then tested and validated repeatedly. These subsystems, in turn, were then integrated into the satellite, a system of systems, in the cavernous workspaces of NRL's Building A59. Field stations also were being primed for the December launch. Looming all the while was a huge cost problem that could put an end to NRL's ELINT satellite run after the next launch. But Poppy was not done yet.

At last, on December 14, 1971, the last block of Poppy satellites was placed in orbit. As always, Mayo and Rose were at Vandenberg Air Force Base for prelaunch preparation and to witness the launch. Mayo then rushed off to a ground station to oversee the initial reception of signals from the satellites.

Only a few months later, the NRO and Navy made an enormous decision that would mark the beginning of the end of Poppy and the beginning of one or more follow-on programs that remain classified. The new architecture of Program C's ELINT collection was laid out in a weeklong gathering at the Naval Security Group's headquarters in Washington, DC, of representatives from all technical, managerial, operational, and other components of the Poppy program. Interestingly, high on the agenda was the same "density problem," which was apparent in the very first glimpse of the GRAB 1 intercepts that Lorenzen, Mayo, and their colleagues heard in 1960 in a small collection hut in Hawaii. "Competing objectives for a system whose collection capability continued to dwarf its processing capability were revealed in briefings and discussion throughout the week," according to one observer. Chipping away at that issue was a data handling system—known as PAPS, for Programming Automatic Processing System—designed with leadership by Hammarstrom, Hellrich, and computer and software engineering colleagues at HRB Singer.¹³⁴

In May 1972, the United States and the Soviet Union signed SALT, the Strategic Arms Limitation Treaty, a nuclear weapons agreement that would provide a new role for overhead ELINT as a means of monitoring treaty compliance. Mayo was called on to specify Poppy's strengths and weaknesses for particular treaty compliance monitoring measurements. Poppy 7, which was launched six months before the signing of SALT, would operate for another five years and would incorporate data processing upgrades along the way. But the actual intelligence data the program harvested and the specific ways the nation used it for strategic and tactical planning and actions, or for treaty monitoring purposes, remains classified.

Nearly 15 years after the launch of the first Poppy satellites, NRL's second ELINT program—after GRAB—was officially closed down. The director of NRO, Dr. Hans Mark, penned the program's epitaph: "The termination of the Poppy program effective 30 September 1977 closes a long and distinguished chapter in the history of overhead reconnaissance, a chapter that began under Navy auspices even before the NRO was established."¹³⁵ Just in case their many bosses changed their minds about the end of program, the NRL team continued to maintain power and other functions

on the satellites that would enable them to revive their ELINT platforms to service. But at a time that remains classified, Wilhelm and his team did command Poppy 7's four satellites to shut off, one by one. Not until 2005 was the Poppy program partially declassified and not until 2012 did the NRO release a heavily redacted official history of Program C.

¹ Ronald L. Potts, *U.S. Navy/NRO Program C Electronic Intelligence Satellites (1958–1977)*, LEO Systems Program Office, National Reconnaissance Office, September 3, 1998, declassified with redactions and approved for release from NRO on June 13, 2012, p. 90.

² Potts, *U.S. Navy/NRO Program C*, pp. 90–91.

³ Potts, p. 93.

⁴ Potts, p. 93.

⁵ W. Craig Reed, *Red November* (New York: Harper Collins, 2010).

⁶ James Winkler memoir, pp. 13–14.

⁷ Winkler, memoir shared with author, pp. 13–14.

⁸ Potts, *U.S. Navy/NRO Program C*, p. 94.

⁹ Potts, p. 96.

¹⁰ Potts, pp. 94–97.

¹¹ Richard D. Easton and Eric F. Frazier, *GPS Declassified: From Smart Bombs to Smart Phones* (Potomac Books, 2013), p. 49.

¹² Easton and Frazier, *GPS Declassified*, p. 100.

¹³ NRL launch manifest; Potts, *U.S. Navy/NRO Program C*, p. 98.

¹⁴ Winkler memoir, p. 20.

¹⁵ Potts, *U.S. Navy/NRO Program C*, p. 98.

¹⁶ COMSAT oral history project, Martin Votaw, http://www.comara.org/legacy/oralhistory/Martin_Votaw.pdf.

¹⁷ Potts, *U.S. Navy/NRO Program C*, p. 100.

¹⁸ Potts, p. 102.

¹⁹ Winkler memoir, p. 20.

²⁰ Patrick W. Binning and Jay W. Middour, "A Brief History of NRL's Early Firsts in Spaceflight," *Advances in Astronautical Sciences* 129 (2008): 1233–1250.

²¹ Peter Wilhelm, interview with TV crew and author at NRL, "GPS Day 2," February 15, 2012.

²² Peter Wilhelm, interview with David van Keuren, November 19, 1987; L.A. Gebhard, *Evolution of Naval Radio-Electronics and Contributions of the Naval Research Laboratory*, NRL Report 8300, 1979, p. 115.

²³ Peter Wilhelm, interview with NRL Historian Leo Slater, August 29, 2009.

²⁴ Wilhelm, interview with Slater, August 29, 2009.

²⁵ Potts, *U.S. Navy/NRO Program C*, pp. 103–106.

²⁶ Lee Hammarstrom, draft of memoir shared with author, November 2013.

²⁷ Potts, *U.S. Navy/NRO Program C*, p. 104.

²⁸ Hammarstrom memoir.

²⁹ Hammarstrom memoir.

³⁰ Hammarstrom memoir.

³¹ Hammarstrom memoir.

³² The Poppy TOG participating agencies included the CIA, NSA, NRO, Office of Naval Intelligence, Naval Security Group, Army Security Agency, and Air Force Security Service.

³³ Potts, *U.S. Navy/NRO Program C*, p. 106.

³⁴ Hammarstrom memoir.

³⁵ Potts, *U.S. Navy/NRO Program C*, pp. 106–107.

³⁶ Chris Dwyer, personal communication.

³⁷ Potts, *U.S. Navy/NRO Program C*, p. 111.

³⁸ Hammarstrom memoir.

³⁹ The antennas were manufactured to NRL's specifications by the company Scientific-Atlanta.

⁴⁰ Potts, *U.S. Navy/NRO Program C*, p. 113.

⁴¹ Potts, p. 116.

⁴² This Special Projects Office was designated as K-4/SP.

⁴³ Potts, *U.S. Navy/NRO Program C*, pp. 116–117.

⁴⁴ Potts, p. 117.

⁴⁵ Potts, p. 117.

⁴⁶ Potts, p. 118.

⁴⁷ Anti-earth-satellite systems would now be called anti-satellite systems.

⁴⁸ Potts, *U.S. Navy/NRO Program C*, p. 119.

⁴⁹ Hammarstrom memoir.

⁵⁰ Hammarstrom memoir.

⁵¹ Potts, *U.S. Navy/NRO Program C*, p. 119.

⁵² These details are specified in a candidacy document for Fred Hellrich (given to the author by Hellrich) for inclusion among the National Reconnaissance Office's "Pioneers," a select group of contributors that NRO considers as standouts in the organization's history.

⁵³ Hammarstrom memoir.

⁵⁴ Potts, *U.S. Navy/NRO Program C*, p. 123.

⁵⁵ Hellrich candidacy document (see endnote 52).

⁵⁶ Hammarstrom memoir.

⁵⁷ Fred Hellrich ran into a snag at first. Even though money became available to upgrade a primary ground station with new computer capabilities, there was not a single suitable computer in U.S. production that was not already called for. While reading a trade magazine, however, Hellrich found mention of one general purpose machine that could work for his purposes, the SEL 810A, built by Systems Engineering Laboratory in Plantation, Florida. He then managed to convince its buyer to let NRL have it and then take delivery of an equivalent machine that SEL would have available six months later. The SEL computer worked on 16-bit words and offered 16 kilobytes of memory. It included a teletype interface, card reader and punch, magnetic tape transports, among other peripherals. Hellrich integrated tape drives made by another company, Ampex. It could interface with the A/DDS that Wald had designed.

⁵⁸ Potts, *U.S. Navy/NRO Program C*, p. 130.

⁵⁹ Potts, p. 130.

⁶⁰ Potts, p. 130.

⁶¹ Fred Hellrich, interview with author, May 16, 2012.

⁶² Potts, *U.S. Navy/NRO Program C*, p. 124.

⁶³ Potts, pp. 124–126.

⁶⁴ Potts, p. 129.

⁶⁵ Potts, p. 131.

⁶⁶ Potts, pp. 132–133.

⁶⁷ Hammarstrom memoir.

⁶⁸ Potts, *U.S. Navy/NRO Program C*, pp. 132–133.

⁶⁹ Potts, pp. 133–134.

⁷⁰ Potts, p. 134.

⁷¹ Potts, p. 136.

⁷² Office of Space Systems, Office of the Secretary of the Air Force, headed by Russell Berg.

⁷³ Potts, *U.S. Navy/NRO Program C*, p. 135.

⁷⁴ Potts, pp. 139–140.

⁷⁵ Potts, pp. 140–141.

⁷⁶ Hammarstrom memoir.

⁷⁷ Potts, *U.S. Navy/NRO Program C*, pp. 140–141.

⁷⁸ Hammarstrom memoir.

- ⁷⁹ Potts, *U.S. Navy/NRO Program C*, pp. 141–142.
- ⁸⁰ A week later, Vietcong and North Vietnamese forces executed what become known as the Tet Offensive, attacking 100 cities in South Vietnam.
- ⁸¹ Potts, *U.S. Navy/NRO Program C*, p. 142.
- ⁸² Potts, p. 143.
- ⁸³ Potts, p. 143.
- ⁸⁴ Potts, pp. 143–144.
- ⁸⁵ Potts, p. 144.
- ⁸⁶ Potts, pp. 144–145.
- ⁸⁷ Potts, p. 146.
- ⁸⁸ Potts, p. 146.
- ⁸⁹ Lee Hammarstrom interview (Moffett Matrix), February 22, 2012; Potts, *U.S. Navy/NRO Program C*, p. 143.
- ⁹⁰ Potts, *U.S. Navy/NRO Program C*, pp. 146–147.
- ⁹¹ Potts, pp. 147–148.
- ⁹² Potts, pp. 150–151.
- ⁹³ Potts, p. 152.
- ⁹⁴ Chris Dwyer, personal communication, February 13, 2012.
- ⁹⁵ Program C's Technical Operations Group, with participants from a host of military, intelligence and other government bodies, set the priorities.
- ⁹⁶ Potts, *U.S. Navy/NRO Program C*, pp. 152–153.
- ⁹⁷ In intelligence parlance, EMLOC refers to Emitter Location.
- ⁹⁸ Potts, *U.S. Navy/NRO Program C*, p. 153.
- ⁹⁹ Potts, pp. 153–154.
- ¹⁰⁰ Potts, p. 154.
- ¹⁰¹ Potts, pp. 157–159.
- ¹⁰² Potts, pp. 159–160.
- ¹⁰³ Ronnie Brooks' rank was Chief Petty Officer.
- ¹⁰⁴ Potts, *U.S. Navy/NRO Program C*. The symbol [REDACTED] indicates places in the Potts history that are blacked out to maintain secrecy of still classified details.
- ¹⁰⁵ Potts, *U.S. Navy/NRO Program C*, pp. 161–162.
- ¹⁰⁶ Potts, p. 163.
- ¹⁰⁷ Potts, pp. 163–164.
- ¹⁰⁸ Potts, pp. 164–165.
- ¹⁰⁹ Potts, pp. 165–166.
- ¹¹⁰ Potts, p. 167.
- ¹¹¹ Potts, pp. 168–169.
- ¹¹² Potts, p. 174.
- ¹¹³ Potts, pp. 174–175.
- ¹¹⁴ Potts, pp. 176–177.
- ¹¹⁵ Lee Hammarstrom would be tasked with working out the technical fix. His solutions proved ahead of their time, but later were implemented by the NRO and NSA in follow-on systems once the technology caught up to his vision.
- ¹¹⁶ Potts, *U.S. Navy/NRO Program C*, pp. 178–179.
- ¹¹⁷ Potts, pp. 180–181.
- ¹¹⁸ Potts, p. 181.
- ¹¹⁹ Potts, p. 187.
- ¹²⁰ Potts, pp. 188–189.
- ¹²¹ Hammarstrom memoir.
- ¹²² Hammarstrom memoir.
- ¹²³ Hammarstrom memoir.
- ¹²⁴ Potts, *U.S. Navy/NRO Program C*, p. 190.

¹²⁵ Potts, *U.S. Navy/NRO Program C*, pp. 195–196. Despite the vote of confidence, Mayo worried that NRL actually was getting shut out of the game it had begun. None of the original partners in NSA from the early days of GRAB, for one, were part of the Poppy team anymore. To Mayo, this absence of personal rapport in the day-to-day management of the program would likely diminish the system's value.

¹²⁶ Potts, *U.S. Navy/NRO Program C*, p. 198.

¹²⁷ Potts, p. 199.

¹²⁸ Potts, p. 199.

¹²⁹ Potts, p. 200.

¹³⁰ Potts, p. 202.

¹³¹ Potts, pp. 205–206.

¹³² Potts, p. 207.

¹³³ Potts, p. 208.

¹³⁴ Potts, p. 216.

¹³⁵ Potts, p. 220.

WHERE AND WHEN, EVERYWHERE AND ALWAYS: THE GLOBAL POSITIONING SYSTEM

The Thor Able Star rocket that carried both GRAB 1 and SOLRAD 1 into orbit within the same shiny spherical shell on June 22, 1960, helped the U.S. space program score several firsts. SOLRAD 1 was NRL's first rocket-based scientific payload since almost all of the lab's space science pioneers transferred to NASA in late 1958. GRAB 1 was NRL's, the nation's, and the world's first orbiting spy payload.

There was yet another groundbreaking payload on that June 22 flight. It was not an NRL payload, but in its navigation function, it would presage one of the most consequential technology developments and achievements the NRL's space technologists and satellite engineers would pull off. Inside the fairings of the rocket's topmost stage, sharing the space with the GRAB 1/SOLRAD 1 sphere, was yet another space pioneer, namely, Transit 2A, a groundbreaking navigation satellite built for the Navy by the Johns Hopkins University's Applied Physics Laboratory (APL). It would evolve into a technology that would become part of everyday life for hundreds of millions of people around the world.

Transit 2A was the world's first navigation satellite to successfully reach orbit. Two prior attempts failed to make it there. Its primary purpose was to enable weapons officers in charge of submarine-launched Polaris missiles to determine, within minutes, their positions at sea within about a fifth of a mile.¹ The Transit program was also known for a time by the secrecy-preserving moniker Program 435, and also by the more straightforward name, Navy Navigation Satellite System, along with the acronym NAVSAT.² The Transit satellites did in fact provide submarines with the capability of determining their locations in about 20 minutes when the satellites were in view of the submarine's location. The geolocation technique in Transit resided in the Doppler shift phenomenon, familiarly experienced as a high-to-low pitch transition like the familiar one heard as a whistle-blasting train approaches and then recedes. After a series of experimental launches, Transit became the world's first operational satellite-based navigation system in support of the Navy's Polaris program. The first positional fix by a Polaris submarine using the Transit system took place in January 1964.

No sooner had a few Transit satellites become operational than did Roger Easton, an NRL engineer who had developed the tracking systems for the Viking and Vanguard programs, come up with the concept for what became known as the Timation

program (derived from the words time and navigation). Easton, whose work would earn him a place among the titans of NRL's long and storied history, started working at the laboratory in the middle of World War II as a junior physicist in the Radio Division's Radio Communication Security Branch. His first project centered on a blind-approach, radar-assisted landing system for aircraft. It was a project with roots stretching to Dr. Ernst Krause, the man who brought V-2 rockets into NRL's research portfolio.³ In the 1950s, as Milt Rosen was building up NRL's Viking rocket sonde program and getting ready to segue into the Vanguard program to put a satellite into orbit as part of the United States' role in the International Geophysical Year (IGY), Easton became a part of the effort. He developed components and systems that eventually would become the Minitrack system for tracking the orbit of Vanguard satellites.⁴

As Easton applied his engineering creativity to this never-before-done satellite-tracking task, he conjectured that the unprecedented precision of atomic clocks, which had been invented in the 1950s, could open up a novel and elegant approach to the task at hand. The technological challenges of the Vanguard program had much to do with Easton's subsequent awakening to the power of extremely precise clocks and their potential to usher navigational technologies into a new era. The design of the Vanguard satellite included then novel and innovative solar cells, but this also meant the orbiting transmitter would emit signals with a power of only a small fraction of a watt—far lower than a transmitter hooked into the power grid or a heavy battery. Imagine looking up from the ground to look at a thousandth-of-a-watt light bulb situated a few hundred miles up and you get the idea.

To compensate for the dimness of the transmission, the Minitrack design, which was primarily the work of Easton and his boss John T. Mengel, called for an array of very large antennas on the ground. With a large enough area, an antenna would be able to gather enough signal power to feed into amplifiers that could reconstitute the original emission from orbit. Several antennas in the array could then be used to determine the angle of arrival of these weak signals so that the position of the satellite, and subsequently the satellite's orbit, could be determined. The first such array of antennas was built at Blossom Point, Maryland, in 1956 in a remote, forested spit of land about 40 miles south of Washington, DC, in the Chesapeake Bay watershed of Maryland, which was then a tobacco-growing region of the state.

The Federal Communications Commission had authorized NRL's Vanguard program to use the IGY-designated frequency of 108 megahertz (MHz) for satellite transmissions. As such, before the Minitrack antenna could accurately determine the satellite's position and orbit, it had to be calibrated to receive signals at that frequency. "Calibrating such a large antenna is an issue unto itself," noted Pete Wilhelm with his usual understatement.⁵

With their signature resourcefulness and connections in the radio world, the NRL satellite tracking team located an FM radio station that was shutting down in

North Carolina. The team bought the station's transmitter, which they had determined was tunable to the top of the FM band where the crucial 108 MHz frequency resided, and moved it to Ft. Monmouth, New Jersey, where the Army already had a large, steerable parabolic receiving antenna that could pick up these signals. According to the team's calculations, the station's new antenna/transmitter combination was powerful enough to reflect and receive 108 MHz signals even from the moon, let alone from an artificial satellite only hundreds of miles away.

To carry out moon-dependent calibrations of the receiving antenna at Blossom Point, Wilhelm explained, Easton and the tracking team at NRL "had to swing this big antenna [at Fort Monmouth] ... at the moon and bounce the 108 megahertz signal off the moon," and as the signal bounced from the moon to the receivers in New Jersey and Maryland, the NRL team would be able to get a calibration.

That was the plan. But then something dramatic diverted their attention. Like the rest of the world, the NRL engineers were stunned on October 4, 1957, when the Soviet Union successfully launched Sputnik. That achievement had stolen the Vanguard team's hope of becoming the first in the world to put a satellite of any kind into orbit, but it suddenly created a great opportunity in the calibration task. "It remains unclear who got the idea first," Wilhelm said, "but someone on the tracking team realized they might be able to capitalize on Sputnik by using it, instead of the moon, for bouncing calibration signals from the Ft. Monmouth transmitter to the Blossom Point station."

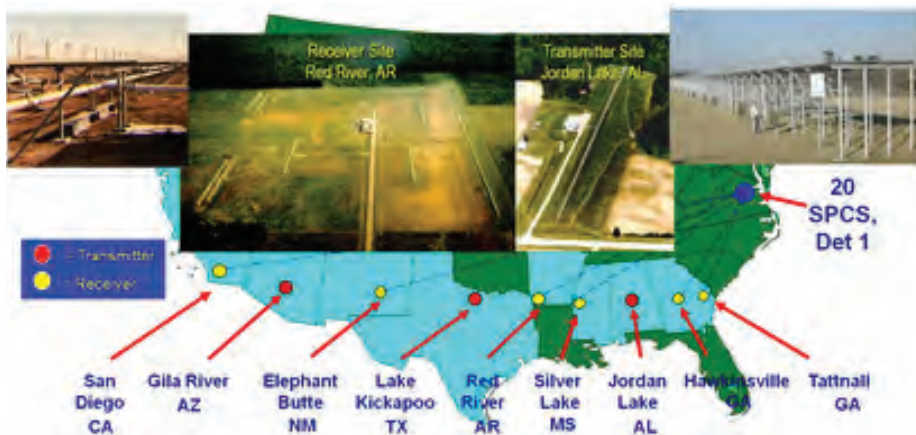
"We had the Army direct their antenna" so that reflections of the antenna's emissions would bounce down toward the receiving antenna in Blossom Point, Easton recalled. "Success was swift," said Easton. "When the satellite went over, we got the reflected signal at Blossom Point. What's more, the signal coming in, now that it was reflecting from an object only hundreds of miles away rather than the quarter-million-mile distance from the moon, was relatively strong." This moment of radio play with Sputnik gave Easton an idea, a very big one as it turned out. "It was the start of the Space Surveillance System," he recounted later.⁶ The system became known as NAVSPASUR (Naval Space Surveillance).

Whereas the Minitrack system was designed to passively receive emissions from a satellite that was sending out radio signals, the detection and tracking system that Easton now had in mind was active. Transmitters on the ground would send fan-shaped probing beams upward into space and receivers would pick up reflections of those signals from anything that happened to be flying through the beam. In February 1958, just weeks before NRL would rejoice in the first successful launch of a Vanguard satellite, Easton prepared a proposal for the Advanced Research Projects Agency (now known as DARPA where the first D stands for the word Defense). The then newly formed ARPA was charged with developing technologies that could be important for the Cold War with the Soviet Union. ARPA had approved NRL's plan for the radar system by June, and within weeks, construction engineers were building

what would become known informally as “the fence.” “The speed with which people reacted in those days was incredible,” said Wilhelm.⁷

The launch of Sputnik meant that more satellites would be placed into orbit, whether by friend or foe, and there was no reason that all would follow Sputnik’s lead in sending out a radio signal to broadcast their presence. An active detection system like the one Easton had in mind would detect any object, publicly announced or not, that was passing through the electromagnetic fence defined by the system’s transmitters.

The plan called for a central large transmitter and two smaller transmitters cutting east-west across the southern United States and a series of receiving sites along the same great circle east-west line to detect the reflected signals. The receiving sites would then fix the angle of arrival of the reflected signals so that the position of the satellite reflecting the signals could be triangulated. Ultimately, the system included three transmitter sites and six receiver sites. The Ft. Monmouth transmitter was disassembled and shipped from its New Jersey location to Jordan Lake, Alabama, to serve as part of the system. Another transmitter was set up near Gila River, Arizona. The central transmitter site, at Lake Kickapoo, near Wichita Falls, Texas, wielded overall the highest power at about 1 megawatt and was the largest, with a length of 11,760 feet. Installation teams built receivers in Fort Stewart, Georgia; Hawkinsville, Georgia; Silver Lake, Mississippi; Red River, Arkansas; Elephant Butte, New Mexico; and San Diego, California.



NAVSPASUR. With its string of transmitters and receivers, the Naval Space Surveillance System (NAVSPASUR) amounted to a radar detection system that would notice any spacecraft passing through it. NRL developed NAVSPASUR out of its Minitrack system for Project Vanguard. Only a few years later, NRL handed the operation of NAVSPASUR over to the Naval Weapons Laboratory in Dahlgren, Virginia. (*AFG-110623-027*, <http://www.peterson.af.mil/news/story.asp?id=123261326>)

If anything flew through NAVSPASUR’s electromagnetic fence, the NRL trackers would know about it. By the time the first and more eastern portion of the system was up and running in the summer of 1958, there were just a few satellites in orbit. A few

pioneering spacecraft, including the first two Sputniks, already had fallen back into the atmosphere and burned up.⁸ But the orbital lanes were slated to get much busier, both with working satellites and with a growing roster of ancillary radar-reflecting objects, including rocket booster bodies that had made it into an orbital trajectory, as well as clamps, panels, and other rocket parts that had blown up into many pieces. This orbiting debris, along with satellites that remained in orbit after they stopped working, eventually would amount to, after a half-century's worth of accumulation, a growing halo of "space junk." Today, this halo has become a massive problem that NRL, NASA, the European Space Agency, and other organizations recognize as a risk to the future of working in space.

Space junk was not a major concern in the early 1960s, however. Just as with the Vanguard program's Minitrack transmitters and receivers, the ones for the NAVSPASUR system needed to be calibrated. When Easton checked in with his colleague and friend Marty Votaw (who at the time was helping orchestrate both the scientific SOLRAD payloads and the classified GRAB payloads) to get that task going, Votaw pointed to Peter Wilhelm, whom Votaw had hired in December 1959. The NAVSPASUR calibration task would involve building a series of satellites, including four spacecraft dubbed SURCAL 1 through SURCAL 4 (SURCAL was derived from "Surveillance Calibration"). These included transmitters, first ones that emitted at 108 MHz, and then ones that emitted at double that frequency, 216.98 MHz. This change would enable the NAVSPASUR system to detect smaller objects. The NRL Satellite Techniques Branch, in cooperation with the NRL space surveillance team, designed and launched another series of payloads of specific shapes and sizes with descriptive names like Calsphere and Dodecapole. These helped NAVSPASUR operators discern more details about how orbiting objects reflected signals from the system's transmitters.

By the time Wilhelm had taken the helm of the Satellite Techniques Branch in 1965, Easton and his group were already working on a straightforward way of upgrading the NAVSPASUR system from primarily a detection system into one that could determine the orbital trajectories of objects in space from data acquired in a single pass rather than several. All it would take, he calculated, was a second line of transmitters and receivers, that is, a second fence several hundred miles south of the main fence.

As Wilhelm recalled it, "Roger realized that, you know, if [there] were two fences that were displaced north-south from each other, so [that a satellite] goes through the first fence and then the second fence only a few minutes later, then now I've got a velocity measurement and I've got enough [data] on one piercing of the [double] fence to determine an orbit, in theory." And so Easton proposed building a second fence at Raymondville, Texas, almost 480 miles south of Lake Kickapoo.⁹ The second fence consisted of a transmitter site and a receiver site east of the transmitter site. This second fence would also demonstrate a new technique, which would reduce the number

of stations needed to fix the position of the satellite penetrating the fence. In addition, the design included ranging signals so that this second fence could determine the range to the object as well as its velocity.

It was an engineering vision in which the solution to one problem, say, detecting any object and its orbit passing over the United States, entailed solving other problems. Those exercises then catalyzed engineers' imaginations in entirely new directions, in Easton's case toward the conceptual basis of the Global Positioning System, known more often now as GPS. A pillar of that conceptual foundation was the use of atomic clocks.

To carry out the necessary calculations for determining the location of satellites from the radio echoes the double fence would receive, the timing of the emissions and receptions would have to be precisely measured. Doing that, Easton knew, would require clocks in the system that could be synchronized within nanoseconds of each other. "That's when Easton had one of those Aha! moments that changes the world," recalled Wilhelm, "Roger gets the idea: Jeez, if I put a clock in the satellite, then I can not only synchronize my two clocks on the ground [in the receivers of the double fence] with the one in space, but I could determine the orbit of the satellite." With a transmitter in the satellite synchronized sufficiently with the receiver on the ground, the range between the two can be accurately measured passively, that is, with no transmissions from the receiving sites. "That's how he gets this idea that putting atomic clocks in satellites is the way to [use passive ranging to] solve the navigation problem, and that's how you get to the GPS concept."¹⁰

The basic geolocation/navigation procedure goes like this: By synchronizing the clock in the satellite with the clock in a receiver on the ground, and then sending a time-tagged signal from the satellite, the time it takes for the signal to travel to the receiver can be precisely determined. Because the signal travels at the speed of light, that time measurement, even though it is but a tiny fraction of a second, accurately and almost instantly reveals the distance between the satellite and the ground receiver.

That is just part of the task to determine a location on the ground from a space-based transmitter. By combining the now-known distance to the satellite with the satellite's orbital location (which can be determined because of tracking systems like NAVSPASUR) when the spacecraft sent the signal, it becomes possible to draw "a sphere of equal range" centered on the satellite. This sphere demarcates all possible locations that are a specific distance from the satellite, but only those points that intersect with the planet are the ones that could coincide with something on the surface. The intersection of two or more such spheres with the planet would indicate with increasing precision the receiver's location on the surface (or with at least three spheres, the location of airborne receivers). If the satellite's location in space and the duration of the signal's trip from the orbiting transmitter to the receiver were known perfectly, and if the Earth also was a perfect sphere, then the calculated sphere would intersect

with the planet in one place that was exactly the location of the receiver. Since perfect knowledge of these factors is not possible, however, it is necessary for the system to feature multiple satellites. By drawing spheres around several signal-sending satellites at different locations in space, their multiple intersection points enable the accurate mathematical determination of a receiver's three-dimensional location. Three satellites provide positions and four satellites can provide time and position, which is what GPS does.

This was a train of thought that required pushing clock technologies to new levels of accuracy and, quite literally, to new heights. In particular, it required that all of the transmitters and receivers have clocks with unprecedented synchronization since even an uncertainty of one-thousandth of a second between the time of transmission to reception of a ranging tone would add an uncertainty in the measured range to the satellite of about 200 miles.¹¹ This meant that Easton and NRL were going to get into the leading edge of precision clock technology.

The first experiments with atomic clocks entailed tedious and time-consuming car transportation of a portable, battery-operated atomic clock for the hundred miles or so between the space surveillance transmitter and receiver pair in south Texas so that the pair's clocks would be synchronized. "We had standards [that is, standard atomic clocks] at the transmitter and the receiver and [used] a traveling clock in between them," noted Easton. "We used to carry cesium beam standards from the transmitter to the receiver to synchronize them."¹² It was a lot of driving that Easton knew he could stop doing if only he could put a good stable clock into orbit. Then he would be able to synchronize both the transmitter and the receiver from the single clock in the satellite.

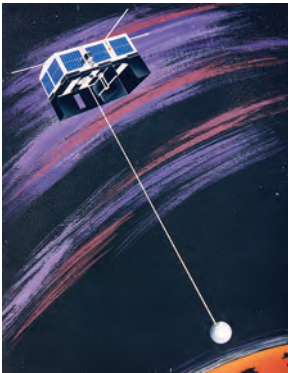
That could solve the clock-synchronization task. "Then came the idea of a ranging signal from the satellite synchronized to a ground station," Easton noted, "adding that would be 'ideal for navigation.'"¹³

Therein lay one of the primary conceptual and technical bases for "passive ranging" and a system of enormous military and civilian significance that would become famous around the world as GPS. "What passive ranging means," explained Wilhelm, "is you have clocks that are so stable that in effect they are synchronized with each other, even though there is no physical connection. They are just that good of a clock."¹⁴ NRL had clock development and timing systems in its research portfolio for many years as part of its work for the U.S. Naval Observatory (USNO), which always has relied on accurate timing technology for timekeeping, for developing its star charts, and for other navigational tools and techniques whose reliability was limited by clock accuracy. Easton could see that the better the clocks, the more any surveillance, tracking, navigation, and location finding system could do. A *raison d'être* for him became, therefore, the development of ever more accurate clocks that could be made satellite-worthy. Wilhelm became a fast convert to this view and then brought to bear everything he could by way of his own ingenuity, connections, and authority

to transform Easton's idea of passive ranging from satellites into a real capability for the Navy and the nation. It would be his Satellite Techniques Branch that would build satellites carrying the clock-bearing payloads.¹⁵

"If you want to know your location to a foot, you need to measure time to one thousand millionth of a second, or a nanosecond. That's how fast the speed of light is," Wilhelm explained. "So to measure and to navigate to high precision, it's all about timing. That's where it starts and that's where it ends."¹⁶

Wilhelm couldn't tell Easton about the classified ELINT payloads that he, Lorenzen, Mayo, and their teams were working on at the time, but he could help Easton secure what essentially would be a free ride into orbit for testing high-accuracy clocks. There was room, Wilhelm knew, on the "aft rack" of the framework on which the next set of Poppy surveillance satellites would be launched on May 31, 1967. The passive ranging satellite carrying a modified commercial crystal oscillator would be called Timation, for "time navigation." That particular launch also had several other satellites slated to be aboard. In fact, it had a record number of payloads for a single launch: seven.



Timation 1. One of the pioneering space tests that led to the Global Positioning System was the NRL spacecraft Timation 1, which was launched on May 31, 1967. Timation 1 tested the concept of sending radio signals from super accurate spaceborne clocks to receivers on the ground as an efficient means of synchronizing clocks throughout the space-based navigation system. Shown here is an artist's depiction of Timation 1 in orbit with a gravity stabilization boom deployed. (NRL photo 69862.jpg and TIMATION 1)

The best space-ready clocks at the time were not atomic clocks. They would have to be based on top-quality quartz crystals (whose crystalline oscillations are akin to a superfast pendulum) that were kept in a temperature-controlled oven so that their crystal structure, and thereby the crystals' vibrational frequencies, wouldn't change, at least not much. The NRL team contracted with the Long Island-based company Frequency Electronics Incorporated (FEI) to modify a land-based production unit for space use. It was about the size of shoebox that was occupied mostly by a pair of temperature-controlling ovens.¹⁷

The heart of these clocks were crystals of quartz mined from the earth, cut into small disks, and then connected to electronic oscillating circuits that set this crystal "tuning fork" going. The problem with them is that the vibration frequencies of the crystals change over time because the crystals are affected by temperature, pressure, contamination, and exposure to radiation, among other influences. All of these, in effect, change the note that the quartz tuning fork generates.

Even so, the FEI clocks appeared to be remarkably stable in Timation 1, but that apparent success was later determined to include a good measure of dumb luck. It turns out that the expected natural drift in the crystal's vibrational frequency was almost perfectly compensated by radiation damage that shifted the crystal's frequency almost the exact amount in the direction opposite to the natural drift. It was a fortuitous result. With an initial eye on improving the quartz clock's stability yet more for Timation 2, the NRL team asked its partners at FEI to redesign the clock for space and to reduce its natural drift. No one knew at the time that this "fix" would effectively unmask the frequency shift due to space-based radiation damage of the crystal. As a result, the "better" clock that went into orbit aboard Timation 2 on September 20, 1969, actually performed poorly compared to the one in Timation 1.¹⁸

If he could have, Easton would have started out using atomic clocks based not on crystals but on atoms in the gaseous state, such as gaseous atoms of the alkali metal cesium. He knew these would produce a more stable frequency, and with that, even more precise clocks. Rather than using crystal vibrations as the timing reference, the vibrations of atomic clocks derive from the almost inviolable vibrations in atomic spectra. Magnetic fields, temperature shifts, and a few other things can, in fact, alter these frequencies, but shielding and temperature control systems can handle those issues. Most important, perhaps, is that the high radiation conditions in orbit do not change an atom's vibrational frequency and so atomic clocks do not "age" and drift the way quartz oscillators inexorably do.

Atomic clocks had been around since the mid-1950s when researchers proposed the idea that an atom's supremely high-frequency oscillation could serve as the basis for ultra-accurate clocks. But initially these clocks were appliance-sized gizmos, weighing hundreds of pounds. Even the commercially available cesium clocks of the time would take a major miniaturization feat to get them small, light, and rugged enough for space duty. So quartz oscillators had to be the way to start.

For the first test of the concept intended for Timation 1, one of Easton's colleagues, Matt Maloof, installed a small transmitter that could send out ranging signals controlled by the Timation 1 crystal clock's output and then put the clock in the back seat of his convertible. He then drove along what was then the new Interstate 295 next to NRL before the highway was even officially opened. A receiver set up in a building near the gate of the lab, and equipped with another quartz clock that had been synchronized with the clock in the convertible, picked up the transmissions.

"So this guy [Maloof] with his convertible goes up on 295 and comes driving down past the lab and they were measuring the range between him and the laboratory and plotting his position as he went," recalled Wilhelm. "Because of that setup, you were able to determine at every instant of time as the car moved past the lab exactly what his range was to an incredible accuracy."¹⁹ This was a time when the Wilson Bridge that crossed from the southwest quadrant of the District of Columbia into Virginia was brand new and just opening up.

With savvy, Easton made sure that representatives from the Navy's Bureau of Weapons were present at the highway demo. Almost on the spot, they wrote a check for \$35,000, the most they were authorized to pay out, to keep development going.²⁰ "They took [the Timation idea], and we started this billion dollar project on \$35,000," Easton noted.²¹ The successor to the Bureau of Weapons, the Naval Air Systems Command, subsequently would continue funding the project in later years, particularly when it came to atomic clock development.²²

That initial injection of cash from the Bureau of Weapons was enough to move forward with the option of carrying out the first satellite test of the Timation concept by placing the quartz-clock-carrying Timation 1 on the Agena launch vehicle's aft rack in the forthcoming Poppy launch.²³ The low cost and afterthought quality of the project would come with limitations. There wasn't much space on the aft rack, for one, and that meant there was not much room for power-generating solar arrays. As such, the transmitter on Timation 1 would only be operable several hours a day before the arrays would have to be devoted to recharging the batteries.

The need for this sort of compromise for future experiments was short lived. Easton was sure he was onto something huge with this passive ranging and he knew that it was going to evolve into an expensive and important national commitment. Cognizant of the politics this would entail, he arranged for a high-profile demonstration of the concept for top-tier Pentagon decision makers, who eventually would be the ones authorizing the many millions of dollars it would take to deploy an operational space-based, global navigation, geolocation, and time-transferring system. In a show of his support for NRL's navigation satellite project, a representative of the Navy's Bureau of Weapons, Chester Kleczek, suggested that a live demonstration take place near the Pentagon in a location offering an unfettered "view" of the satellite as it began its 13-minute pass traced across the bowl of the sky. The location he suggested was near the Lincoln Memorial on the east bank of the Potomac River by a stone memorial for John Ericsson, a prolific Civil War era inventor, builder of the Monitor (an ironclad gun boat), and the screw propeller, which stands as one of the most important advances in the history of naval propulsion.²⁴

To prep for the demo, scheduled for October 25, 1967 (just a few months after Timation 1's launch), Easton's NRL colleague James Buisson traveled from NRL to the Naval Weapons Laboratory in Dahlgren, Virginia, where technicians working with TRANET (which stands for Transit Network), a Doppler-based tracking system, had been tracking Timation 1. Buisson picked up magnetic tapes containing a full record of Timation 1's orbit, or ephemeris, which was classified at the time. Then, together with Space Applications Branch colleague Howard deVezin, they converted the data into input suitable for a computer program that could predict the range and azimuth of the Timation payload as it made a pass over the demo site on the National Mall.²⁵

On the day prior to the demo, another colleague, Thomas McCaskill, took the next step by converting the computed outputs into a range-intercept chart, several

copies of which the Timation team would lay out in front of the VIPs at the demo site. Even though this “range-intercept, line-of-position method” was not part of the operational concept, it was a savvy prop for the demo because some of the invitees, among them high-level Navy officers, would be familiar with this celestial navigation technique from their own at-sea duties with the Fleet.

October 25, a Wednesday, was a brisk autumn day. A contingent of NRL engineers in three unassuming vehicles—a gray pickup with the NRL logo in the lead, followed by a Ford coupe and a Pontiac sedan—made their way from the lab to the Ericsson Memorial. With Easton supervising the team, Buisson and McCaskill, and other colleagues Don Lynch, Al Bartholomew, and Alick Frank, all got to work unloading and setting up the equipment. On top of a plywood sheet set onto two saw horses went the steerable Yagi antenna that would pick up Timation’s signals, receiver electronics, a portable cesium atomic clock, a chart paper recorder, a couple of marine batteries, and a DC-to-AC converter. The satellite would approach from the southwest and sweep across to the northeast.²⁶

Soon after they set up the gear, two cars with Navy and Department of Defense (DoD) identification marks parked near the memorial. A half-dozen VIPs from the Naval Air Systems Command (NAVAIR), the Office of the Director of Defense Research and Engineering (DDR&E), and the Office of the Chief of Naval Operations (OPNAV) emerged from their vehicles. Easton escorted them to the makeshift table now burdened with a full-service receiving setup. Kleczek was there too, anxious to see how well his suggested demo venue would turn out.

Easton explained what was going to unfold during the demonstration as one of his colleagues taped a range-intercept chart to the table and passed a few more charts around for easy reference. On the charts, lines splaying out radially like spokes from hubs were segmented with tick marks corresponding to specific times, which corresponded to the distance (time multiplied by the speed of light equals distance) to the satellite. The stage was set.

On cue, Timation 1 soared above the horizon and began its pass over the demonstration site. Pens on the chart recorder jumped into action, indicating that the receiver had begun picking up signals from the satellite. Timation 1 quickly cycled through the sequence of tones, or frequencies, whose time of travel between the satellite and the receiver was the all-important parameter to be measured and plotted in order to determine the distance to the satellite. Each of the tones, which increased in frequency, produced another datum that reduced the overall uncertainty in the ultimate range measurement. With each range measurement, the VIPs could draw another line of position on the range-intercept charts. The intersections of these lines enabled the participants to track how the navigational fix on their own ground location became better defined with each additional signal received from Timation 1.

The demonstration hit the mark, as evidenced by the subsequent Pentagon-level decision to fund the satellite navigation project that Easton had first envisioned three

years earlier. The October 25 demo would be just the first of many that Easton ran, including one for a dozen Navy captains at NRL in Building 53 where Easton had his office and labs and that would become one of the nation's premier testing and certification grounds for the DoD's highest-precision atomic clocks. For that demo, Easton shunted live satellite data into the demonstration room where the captains then could determine their own geolocations.

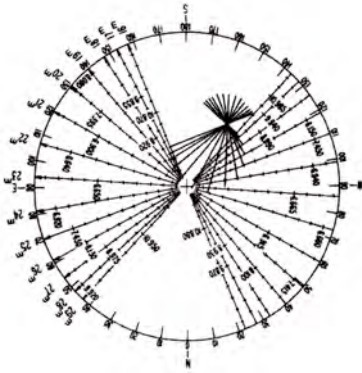


Chart Art. In a key demonstration of the Timation concept, high-level observers were able to use a familiar navigation charting technique to convert data from a satellite passing overhead into a determination of their own location on the National Mall in Washington, DC. An example of such a chart is shown here. (*Chart Record*, scanned from page 61 of *Whitlock and McCaskell, "NRL GPS Bibliography."*)

To show the system's versatility and potential value to all the nation's military services, Easton orchestrated more tests—from boats, land vehicles, and aircraft. Time-transfer tests using the satellite's clock to synchronize clocks on the ground with an accuracy better than one microsecond were undertaken with the U.S. Naval Observatory in 1967. Five months later, tests were done with the National Bureau of Standards (now known as the National Institute of Standards and Technology) at its facility in Fort Collins, Colorado.²⁷ The orbit determination group at Dahlgren, Virginia, at the Naval Weapons Laboratory, produced the orbital positions of Timation in preparation for these navigation and time-transfer demonstrations. To expand the types of experiments and tests that were possible, the Timation team set up fixed ground receiving stations and a portable receiver which could run for 8 hours on marine storage batteries. Among other equipment, ground stations included a cesium atomic clock, data recorder, and processors for comparing the phase differences between received signals (important for precision range calculations) and reference signals.²⁸

The entire system of clocks in the Timation 1 network ultimately was anchored to the DoD Master Clock on Massachusetts Ave., NW, in Washington, DC, on the grounds of the USNO (United States Naval Observatory). The initial setting of Timation 1's quartz clock entailed lugging a portable atomic clock to USNO, setting it in synchrony with the master clock, then carting the newly synchronized portable atomic clock to Blossom Point, Maryland, where the ground station's own cesium clock was then synchronized using the portable relay. Via telemetry, that standard time then was used to set the quartz clock on the Timation satellite.

It all paved the way for Timation 2, launched along with the Poppy 6 payload on September 30, 1969, just two months after the triumphant Apollo 11 landing of the first humans on the moon. These satellites were boosted along with an unprecedented group of seven other satellites aboard a Thorad Agena D booster (so-named because its Thor stage featured an extended fuel tank and strap-on boosters), which finessed the payloads into a 500-mile polar orbit. The quartz crystal clock oscillator featured four ovens to provide more precise temperature control and longer-duration stability. The quartz crystal operated at 5 MHz, supporting the transmission of ranging frequencies of up to 1 MHz. That opened the way to a clock precision of 30 nanoseconds, which would result in a geolocation accuracy of tens of meters.²⁹ The Naval Weapons Laboratory³⁰ in Dahlgren again provided orbit-determination services by tracking Timation 2 via Doppler measurements with its TRANET system (Transit Network, developed for global geodetic determinations).

Also weighing in here was the Princeton, New Jersey-based RCA Astro-Electronics Division, which NRL contracted to develop Timation receivers and study architectural options for the overall Timation system. Among the latter were investigations into the relationship of, on the one hand, the types and capabilities of the orbiting clocks and, on the other hand, the satellite constellations that would make for practical, global coverage.³¹



Timation 2. Though not very pretty, the Timation 2 satellite was part of the important process of testing the performance of highly accurate quartz clocks for a space-based navigation system that would become known as GPS. Timation 2 was launched into orbit on September 30, 1969. (NRL photo D-250.jpg)

Compared to its predecessor, Timation 2 was a bit bigger and had more power available for its components, including a transmitter that sent an extended pattern of range tones on two carrier frequencies of 150 MHz and 400 MHz. This was a technical requirement for reducing uncertainties that resulted from ionospheric refractive effects (variations of the signals' phases) as well as for improving the system's geolocation accuracy. "We got fixes of about fifty meters RMS [root mean square]," Easton said, referring to the distance between an actual location of a receiver on the ground and the one determined by the Timation system.³² Another successful experiment with Timation 2 demonstrated a time-transfer from the nation's premier standard clock at the USNO to another of the world's primary time standards at the Royal Observatory in London's Greenwich district.

"We were able to synchronize the two master control stations in London and Washington to incredible accuracy, fractions of a microsecond," said Wilhelm. "That

was the first time satellites had been used to do this [passive] time transfer” between different nations’ master clocks. As impressive as that was, Easton could tell that he would need to fly even better clocks if his vision of satellite navigation was to become as valuable of a technical asset as he had hoped. “We got a lot of data and we could tell that the quartz oscillator wasn’t working too well, and we ought to get something better,” he said.³³

Easton needed better clocks. However, they were only part of the system that would depend on a constellation of dozens of satellites. The satellites would be arranged in an orbital pattern such that anybody anywhere on the planet with a suitable receiver and enough calculating power would be able to determine their location with unprecedented precision. Accuracy was to be attained from ranging signals from at least four satellites.

The pieces were coming into place for a system that would satisfy the Joint Chiefs of Staff (JCS) navigation requirements first laid out in 1968.³⁴ These requirements called for worldwide, continuous, three-dimensional position determination with an accuracy of 50 feet, or about one hundredth of a nautical mile, with passive user equipment. As Wilhelm recalled it, “the [JCS] study said, okay, these are the requirements that we want your navigation system to be able to meet, and it was ... for all military users—aircraft, ships, ground troops, trucks, tanks, whatever, anywhere on the surface of the Earth. And when you look at those requirements, it drives you to where we’re at today.”³⁵ If the system were only for naval vessels, which are at sea level, it would only need to determine a ship’s longitude and latitude, a two-dimensional problem. But the Joint Chiefs of Staff, Wilhelm stressed, “said ‘no, we want 3D’ and that’s what drives you to the numbers of satellites that we are talking about here, 24 or 28 satellites, something on that order.”³⁶

It was clear that this emerging technology, if it were to serve the needs of all military users, would be complex and expensive and that every effort should be taken to get it right and in an affordable way. To strive toward that goal, the DoD set up, in the 1968/1969 time frame, the DoD Navigation Satellite Executive Steering Group, or the NAVSEG.³⁷ The system that was to result from the studies sponsored by the NAVSEG was to be known as the Defense Navigation Satellite System (DNSS). Because aircraft posed the most demanding navigation problem, parameters for those became the driving framework for the system studies by the NAVSEG as it examined the various proposals and options on the table, including the primary Air Force contender known as 621B.

The Air Force’s 621B proposal had the same goal as NRL’s Timation approach, but there were significant differences. Easton got a good bead on that program in 1968 at a meeting at the U.S. Naval Observatory where NRL and the Air Force both presented classified papers on their respective proposed systems.³⁸

For one thing, the Air Force proposed using satellites in geosynchronous orbit, which is to say high-flying satellites that orbit at an altitude of about 22,000 miles and

in complete synchrony with the rotating Earth below. This way, the satellites stayed over the same spot on the ground continuously. For a particular quadrant of the planet, there would be one satellite over the equator in a geosynchronous orbit and three others associated with it in orbits that were tilted (inclined) with respect to the first one and highly elliptical rather than circular. “If you did a trace of the [overhead motion of the] four satellites on the ground, it looks like three figure eights crossing over where the center satellite is. So we called that the eggbeater configuration,” Wilhelm explained.

The engineering of the system left the Navy uneasy. The configuration, for one, would leave Earth’s poles poorly served, yet the country’s nuclear missile submarines were routinely patrolling in these regions and were among the military assets most in need of a navigation satellite system. So from a Navy standpoint, the Air Force proposal was “totally unacceptable,” according to Wilhelm.³⁹

Also problematic, according to the NRL contenders, was the eccentricity of the satellites in the 621B proposal. Maintaining satellites in those orbits, as the sun and moon tugged on the spacecraft to differing degrees day by day, would require relentless on-the-fly corrections, which would take a lot of propulsion engineering and propellant, thereby reducing each satellite’s lifetime. Yet another drawback, as the NRLers saw it, was that the loss of any one satellite in any of the four-satellite configurations would take away the capability of determining locations in three dimensions in that quadrant of the planet. Without redundancy in the system, there would be a great risk of losing important aspects of the navigational system at any moment, including during wartime when the country could least afford the loss.

The list of drawbacks, as Easton, Wilhelm, and the Navy saw it, was yet longer. If the 621B concept were to cover the entire planet, two of the four four-satellite configurations would require ground stations to be placed outside of U.S. territory, which meant it would be hard to protect them. The Air Force system also called for transmission of time data and signals from a ground station underneath each constellation because the satellites themselves would not carry atomic clock time standards the way the Navy program would. A related drawback the NRL team raised was that the highly elliptical orbits would impose a relativistic effect on the time signals that would require constantly updated mathematical corrections to be built into the processing part of the system.⁴⁰

So here was a case of two military services proposing their own respective versions of the most ambitious navigation system the world had ever seen. The country did not need and could not afford two such systems, so the Navy and the Air Force were going to have to figure something out and the point of the NAVSEG was to help these rivals do just that.

Easton was the NRL representative on NAVSEG, which met periodically from 1968 until 1972 to work out differences into what in the end would be a single navigation system. “We would go and each one would tell what they were going to

do, and the other ones would throw stones at it," Easton said.⁴¹ Consequently, Easton and others in the loop executed numerous calculations and ran many simulations to determine the best heights, trajectories, inclinations, and other orbital parameters for a constellation of satellites to provide the coverage needed.

"The initial design that they [NRL] came up with was [a constellation of] satellites in about 7,500 nautical mile circular [polar] orbits, which were high enough to be in the line of sight from a large area on the planet," Wilhelm recalled.⁴² "Twenty-seven satellites in eight-hour orbits, arranged in three planes, would provide global all-the-time coverage. The team realized [they] needed to avoid elliptical orbits, in which the satellite would travel at a height that would vary during each orbit, because those changes include varying velocities and passage through different gravitational fields, all of which affect the clocks in accordance with the theory of relativity. This was one of the few technologies ever devised for which relativity was a real factor, not just a theoretical one."⁴³ In their quest to optimize the system architecture and after numerous simulations, Easton and his team finally proposed a constellation of satellites in three inclined orbits to provide the best coverage for users anywhere in the world.

It would not be an easy feat getting dozens of satellites into orbits 7,500 miles overhead, let alone at an affordable price. The initial proposal was to use a large booster and put multiple satellites in each orbit plane at the same time. So deploying a full navigation satellite system was clearly going to be an expensive proposition. The NAVSEG attempted to resolve the different technical concepts but could not come up with a clear direction regarding the best system concept to implement. The NAVSEG finally proposed a demonstration project that would implement enough of the competing concept technologies to generate sufficient data for guiding its recommendation regarding which concept to green-light for full development. In April of 1972, Dr. John S. Foster, Jr., the DoD Director of Defense Research and Engineering (DDR&E), formalized the task of selecting the optimum system by circulating to the Military Departments the draft Development Concept Paper (DCP) Number 121 titled "The Defense Navigation Satellite Program Demonstration Program (DNSDP)."

To consolidate its space projects, the Navy recast sponsorship for NRL's Timation and other satellite initiatives with other Navy Space projects by disestablishing the Astronautics Division of the Naval Air Systems Command and moving the projects it oversaw into a newly formed Navy Space Projects Office, designated as PM-16.⁴⁴ This office became the programmatic home of all Navy space projects. At the same time, the Navy continued support for the Timation option for the DNSS by calling for the development of experimental satellites to prove out the technology required for the system. To comply, Easton and his satellite navigation team at NRL developed a demonstration plan consisting of four experimental satellites. The first step was to begin designing and fabricating what the team referred to as Timation 3A, but which when completed and launched in 1974 was renamed Navigation Technology Satellite One (NTS-1) to reflect its inclusion in the newly formed GPS program.

In a move in April 1973 that greatly concerned the NRL pioneers in space-based navigation and their partners within the Department of the Navy, the Deputy Secretary of Defense sent out a memorandum designating the Air Force as the executive service overseeing the DNSDP. The Air Force was charged to proceed with development of a plan that would demonstrate the capability to meet the needs of all the military services, not just the Air Force's, but that did not put the Navy at ease. A Joint Program Office (JPO) was set up at the Air Force Space and Missile Systems Organization (SAMSO) to orchestrate the collaboration among the stakeholders—primarily the Air Force, Navy, Army, and Marine Corps—to spell out a plan for the DNSDP. Originally the system was to be named the Defense Navigation Satellite System, but it ultimately would be designated as the Navigation Satellite Timing and Ranging Global Positioning System, or NAVSTAR GPS for short.⁴⁵ The first JPO program director was Colonel Bradford W. Parkinson of the Air Force, who earned a Ph.D. in aeronautics and astronautics from Stanford University in 1966 and who would work on the satellite navigation task with representatives from the Army, Navy, Marine Corps, Coast Guard, Defense Mapping Agency, Air Logistics Command, and NATO.

Colonel Parkinson was directed to develop the demonstration program as a joint development effort. The demonstration was to include the path to the final system design, which the DoD would approve before the program would proceed with full-scale development, according to a historical account by Parkinson himself, along with coauthors that included NRL atomic-clock and GPS expert Ron Beard.⁴⁶ Credit for the name that stuck for the system, NAVSTAR Global Positioning System, goes in part to General Hank Stehling, who was Director of Space for the Air Force Deputy Chief of Staff for R&D. Because the system's concept went beyond mere navigation, he suggested that the term "global positioning system" more fully encompassed the planned deliverable.

The NAVSTAR part of the moniker (that is, Navigation Satellite Timing and Ranging) came from John Walsh, a Deputy Director for DDR&E who was part of the decision-making infrastructure regarding budgets for strategic systems, including satellite-based global positioning schemes. During one of the many budgeting discussions associated with the NAVSTAR GPS program, Walsh suggested to Colonel Brent Brentnall, the Department of Defense representative for the program, that NAVSTAR had a nice ring to it. "Col. Brentnall passed this along as a good idea to Dr. Parkinson, noting that if Mr. Walsh were to name [the program] he would undoubtedly feel more protective towards it. Dr. Parkinson seized the opportunity," according to the historical account by Parkinson, Beard, and their coauthors. Joining NRL in 1971, Beard (who just previously had been the Timation program manager for the sponsor at NAVAIR) would become a primary NRL representative and advocate in many of the technical, policy, and programmatic meetings that would take place over the decades it would take for GPS to become a fully operational system. In time, he would oversee the GPS Joint Clock Development Program and the still-continuing role of

NRL in the maintenance and monitoring of the Global Positioning System's network of atomic clocks.⁴⁷ NAVSTAR Global Positioning System became the official name, though most would later drop the acronym and shorten "Global Positioning System" to its acronym, GPS.



GPS Champion. A member of the NRL team that developed space-worthy atomic clocks, as well as the overall architecture of what became known as the Global Positioning System, Ron Beard is shown here at his desk in the Aerospace Systems Branch (Code 7969) in 1984. (*NRL photo 81070(8).jpg*)

Despite agreement on a name for the future navigation satellite system, there was no agreement about just what aspects of the dueling Navy and Air Force proposals the system would embody. To move toward agreement about those specifications, about the time Colonel Parkinson was scheduled to give a briefing on the evolving Development Concept Paper to the new DDR&E, Parkinson called a meeting over Labor Day weekend in 1973. This meeting later would be viewed by some as a pivotal moment in the history of the GPS technology. About a dozen military and civilian members of the Joint Program Office met on the fifth floor of the Pentagon.⁴⁸ That was not the only pivotal meeting convened that weekend, according to Roger Easton's son, Richard, who published a history of GPS in 2013.⁴⁹ According to recollections of his father, Richard Easton writes that Roger Easton and Captain David Holmes (retired), who years earlier had been an influential liaison with the Advanced Research Projects Agency (ARPA) and helped fund the lab to develop the NAVSPASUR system, met at the Spring Hill Motel at Bailey's Crossroads, Virginia, with Parkinson and other Air Force representatives.⁵⁰ It is this motel meeting that Beard argues was most influential in determining the ultimate framework for GPS.

Arriving at an agreement about a system for the nation took seemingly endless hours of discussion, but the upshot was this, Wilhelm recounts: "A suggestion was made to [Parkinson], 'why don't you just take the Navy system and you guys [that is, the Air Force] manage it, but we'll go with the Navy approach, the Navy clocks in the satellites, the Navy high circular orbits, and we'll fly both [the Navy and Air Force] ranging systems.'"⁵¹

And that, essentially, is how it went down.⁵² Colonel Parkinson proceeded to revise the draft development concept paper for the extensive series of briefings at the Pentagon necessary to inform tri-service and Department of Defense leadership about the plan that would be presented in late December 1973 to the Defense Systems Acquisition Review Council (DSARC). The council did not take long to approve a demonstration of the system concept.⁵³

The approval memorandum stressed that NRL was to play a key navigation technology role and develop the all-important clocks for the system. Cesium-based standards looked like the best candidates for the operational system. The DCP called for the building of additional technology satellites, including the NRL-designed Timation 3A (or NTS-1) and two additional NRL satellites, which were to be known as NTS-2 and NTS-3. In December 1973, the DSARC green-lighted the Global Positioning System by approving, in addition to the NTS-1 satellite, a demonstration constellation of NTS-2 and three Air Force developed satellites in 12-hour inclined orbits, which was essentially the demonstration configuration NRL had been pushing for.⁵⁴

In the discussions and coordination leading up to the finally presented DCP, “Roger had laid out the grand plan, but how do you implement it” was the question, Wilhelm said.⁵⁵ It fell on Wilhelm’s shoulders to answer that question. The cost issue was being forced also because the Thor Agena family of boosters that NRL relied on for launching the two Timation satellites were being discontinued, entailing a likely move to Titan boosters. This was an expensive booster, potentially adding a considerable cost to the concept demonstration and jeopardizing the approval of the GPS program.

This is where Wilhelm came in with his engineering creativity that would earn him, in time, a prestigious collection of technical and public service awards from the government. Rather than using either a Titan or Thor Agena booster, he identified a dirt-cheap alternative. He knew unused Atlas F boosters, which were designed for delivering ICBMs to enemy targets, were available since they were now being superseded by Boeing’s next-generation Minuteman boosters. The Atlas F was becoming obsolete for delivering nuclear bombs for a good reason. It was a liquid-fueled rocket that ran on kerosene mixing and burning with liquid oxygen. The fuel had to be loaded in the missile’s silo under cryogenic conditions only when the rocket needed to be launched. If that moment came, the fueling process would have to be carried out, the rocket then would have to be elevated to the surface, and then the engine would have to be ignited to send it and its nuclear warhead on its awful way. It all took time. “That time duration was of concern because, after all, you think you’re under attack so the other guy has already launched and they are coming at you and you want to make sure you can get [yours] off,” Wilhelm explained. The Minuteman ICBMs relied on solid fuel motors and could sit there ready to be launched within minutes of an order to do so. “All you need to do is hit the button and she’s gone,” said Wilhelm.⁵⁶

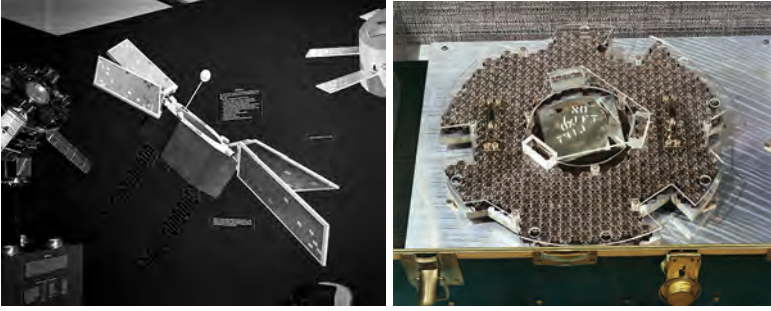
Wilhelm was impressed by the weight the Atlas F boosters could carry aloft and by their guidance systems. Combine those features with the low cost that came with their surplus status, and they looked to Wilhelm like an ideal way for NRL and the taxpayer to continue developing what he could see could become a revolutionary new means for military navigation and, as it would turn out, much more than that.

His calculations indicated that these missiles could take a reasonably sized payload to a 100-mile altitude. Furthermore, he concluded, by adding a controllable upper stage to the Atlas F, the upper stage would then be able to insert payloads into much higher circular orbits. This would help Easton and his colleagues demonstrate that the Timation concept worked and could be deployed far more affordably than with a Titan launch.⁵⁷ With the approval of the GPS concept demonstration plan, Wilhelm and NRL got the green light to pitch the plan for future payload designs and launches.

Wilhelm worked with the Space Test Program office within the DoD that was going to fund the launch of the technology satellites as part of the DoD program to put experiments into space for investigating navigation satellite concepts. Collaboratively they designed the NTS-1 launch system that took a surplus Atlas booster and topped it with a solid-propellant rocket stage that took the satellite up to the 7,500 nautical mile orbit as planned.

FEI again built a pair of quartz oscillators especially for the NTS-1 satellite as the primary timing devices. But for the first time, rubidium-vapor atomic clocks small enough and with a design that would be compatible with a satellite became available. Easton's clock development team bought a half-dozen of these from the Munich, Germany firm Efratom, and ran tests that confirmed the clocks could be space qualified. So at a point later in a satellite development program than is normal for major changes, the NTS-1 team decided to include as an experiment a pair of rubidium clocks along with FEI's quartz oscillators. This required Easton and his fellow clock specialists to modify the Efratom models for the rigors of launch, so they could be remotely operated, and so they would work with the rest of the satellite's electronics.⁵⁸ "We just picked up [six] that the Germans [Efratom] had developed," Easton recounts. "We put lead around [a pair of] them so they wouldn't be affected too much by radiation and flew them. They were significantly better than the quartz crystals that we had flown previously."⁵⁹

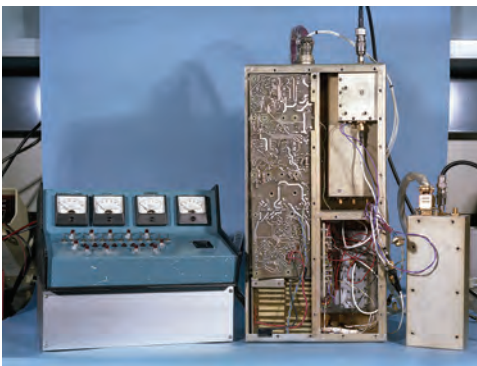
In addition to hosting the first tests of atomic clocks in space, the overall plan for NTS-1 that came out of deliberations of the NAVSEG was to host a transmitter system that was part of the Air Force 621B test program at White Sands, New Mexico. As opposed to Easton's so-called side tone ranging (STR) signal, the 621B approach was to use a ranging signal protocol known as pseudo random noise (PRN). NRL would provide the antenna, power, and telemetry components and the Air Force would provide the transmitter. Also on board NTS-1, on the bottom of the satellite, would be an array of laser retroreflectors as part of the NASA program that was developing a



NTS-1/Timation 3. The third test satellite built during the developmental phase of the Global Positioning System (GPS) was known at NRL as Timation 3, but was renamed as NTS-1 as the participants in the program grew well beyond NRL. Shown here is a model of the satellite that was on display in a mini-museum in NRL's Building 222, and a retroreflector array that flew on NTS-1 to test optical tracking abilities. (NRL photos 77112(30).tif and 77328(3).jpg)

laser-based tracking and ranging network for studying the dynamics of Earth's crust. To eke out yet more experimental value from the satellite, the NRL team built radiation dosimeters for measuring the radiation environment during NTS-1's operation. The scientific payload also included a variety of solar arrays of different designs and different makers for a comparison study. The pieces for the next-generation navigation system were coming together.

Even as preparation for the first on-orbit test of the rubidium clocks was moving forward, the NRL clock team was already busy developing what was presumed would be an even better atomic clock based on the element cesium. A cesium standard was considered to be about 10 times more accurate than the rubidium standards, based on comparisons between the two. The NRL engineers also were well aware that more stable and accurate clocks were needed in the higher orbits selected for the satellites in the GPS concept since the satellites would be out of view longer from U.S. based ground stations used to update the clock. This enabled each satellite in the constellation to have a larger view of the Earth. That, in turn, meant the entire system would require fewer satellites in orbit for global coverage. As such, the NRL team, as it thought forward to NTS-2 and the demonstration constellation that it was to be a part



Atomic Clock. Pivotal both to orbital tracking and to a system like the Global Positioning System are superlatively accurate atomic clocks. Shown here is a cesium-based atomic clock during a testing phase at NRL. Such clocks would gain or lose only 1 second in 3 million years. (NRL photo 78336(1).jpg)

of, considered the problem of the satellites flying at 11,000 miles rather than 7,500. It was a move that had its compromises.

For one thing, it would take a larger booster to take a payload to the higher altitude. Wilhelm's proposal was to take the surplus Atlas boosters and top those with a more capable and lower cost solid-propellant rocket stage that could take a substantial payload all the way to the 11,000 nautical mile orbit. The result would be an on-the-cheap booster (which featured a novel tandem configuration of two solid rocket motors) for the high-flying navigation satellites.⁶⁰ The Atlas F itself couldn't go as high as the satellites needed to get, but it would reach its highest point, its apogee, under a precise guidance system. The idea then was to build an upper stage that combined additional boosting power with a technique known as spin stabilization, by which a well-balanced object set spinning would maintain a trajectory it was initially set on.

The company selected to build the upper stage for NTS-2 was Fairchild, a company that Wernher von Braun (of V-2 and then NASA fame) would join in 1972 as vice president, in collaboration with a small Virginia rocket company called Atlantic Research. Their solution was in the form of a manifold that looked like four nozzle-bottomed, gas-emitting bottles and a lot of plumbing, all of which was designed and machined so precisely that as gas vented from the bottles, it generated just the right spinning momentum to stabilize the satellite along the path that the guided Atlas rocket had initiated. Getting the navigation satellites into the orbit that Easton and his colleagues calculated as the best one would require the tandem, two-rocket configuration on the spin-stabilized stage.⁶¹

First things first though, and that meant NTS-1. On July 14, 1974, NTS-1, which NRL continued to name as Timation 3A for a while in its own list of launches, became the first satellite to go into orbit from the SLC-3 West launch pad at Vandenberg Air Force Base, which was the one Wilhelm had convinced the National Reconnaissance Program (the sponsor of the Poppy ELINT program) to renovate so that it could accommodate Atlas F liquid-fueled boosters.⁶² It was also the one used for NTS-2, which would launch on June 23, 1977, the same year the Poppy program would come to an official close. It would also launch the next 12 Rockwell-built Block I GPS satellites.

Launching Atlas boosters was no small commitment. The cryogenic liquid fuel required that, prior to launch time, liquid oxygen had to be continually pumped into a tank to replace the oxygen as it evaporated. The filling technique was not perfect and liquid oxygen spilled down into a concrete basin underneath the launch stand known for good reasons as the flame bucket. Some kerosene would drip too, but a lesser amount. "If you have a nice cold night and a long countdown, you can drop a lot of kerosene with [the] gelled oxygen and it can coat the flame bucket," Wilhelm noted,⁶³ "and that's what happened ... on the second launch [at the modified pad at Vandenberg]. The launch after NTS-1 was an RCA weather satellite and it didn't go well. The flame bucket's contents ignited and blew the rocket and its satellite into bits.

It was the most spectacular failure I had seen,” Wilhelm says. “And the fact that our [first] launch had roughened the surface of the concrete, there were now a lot of pits in there from the hot flame and everything so there was a place for the stuff to puddle up.”

It was a powerful and expensive lesson. After that, the flame bucket was resurfaced into a smoother condition that would not harbor dripping fuel and a “water deluge” was installed that would wash any spilled fuel down conduits and into collection containers before it could accumulate underneath the rocket.⁶⁴

Meanwhile, NTS-1 was orbiting the planet. The experiments conducted with this mission provided crucial data on the performance of the rubidium clocks. For example, the mission tested the transfer of navigation and time data between the satellite and the NRL system’s ground components, and those exercises helped open the way for the subsequent mission, NTS-2, which would prove to be the first satellite to fly in the 12-hour GPS orbit and to transmit the GPS signals.

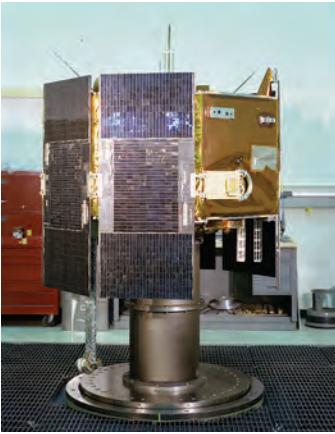
A memorandum following the approval of the first phase of GPS development from the Director of Defense Research and Engineering was circulated in late 1974⁶⁵ specifying a parallel development of cesium clocks by NRL. NRL was to develop both a primary cesium clock and a second version from an alternate source so that the supply of production models could be assured for the larger numbers of GPS satellites that would come on line in the years ahead. Moreover, the memorandum also provided the guidance that if both versions proved to work well and reliably enough, then both the cesium clocks would be tested on NTS-2 and one would become the clock of choice for the GPS system after the first planned block of six GPS satellites that Rockwell International would deliver. To push the clock technology even further, NRL was later tasked with developing hydrogen masers, that is, hydrogen-based atomic clocks that were even more stable than cesium clocks. The first idea was that these were to find duty in the ground segment of the GPS system and if successful the NRL clockmeisters would subsequently design lighter, miniaturized versions for use in space. The overall development schedule even had an experimental maser flying on the NTS-3 mission.

“NTS-3 never happened,” Wilhelm noted,⁶⁶ but maser development by both NRL and contract researchers did build some momentum. For example, Easton’s group managed two industrial hydrogen maser R&D teams, one at Hughes Research Labs and one at RCA, with the charge of trying to build and validate experimental space-capable hydrogen masers. Beard pointed out that during the operational deployment of GPS, a hydrogen maser actually was designed and built for GPS satellites. Even so, no maser has yet to be deployed in the system. Remnants of the maser research reside at NRL in Building 53 where there is a veritable atomic clock museum with specimens of each generation of atomic clock that was under consideration or development for the Timation and NTS satellites.

On June 23, 1977, NTS-2, the last satellite in the GPS program that NRL engi-

neers would build, made it into orbit atop an Atlas F from Vandenberg Air Force Base. It would test about every major component that Rockwell International would use in its demonstration GPS satellite. The NTS-2 test bed also would validate the JCS-required three-dimensional accuracy of less than 60 feet with aircraft flying over a calibrated test range.⁶⁷

On board NTS-2 were the world's first two cesium clock prototypes built under the guidance of, and for, NRL by Massachusetts-based Frequency and Time Systems Inc., to fly in space. These clocks performed extremely well, achieving a time error of about 20 nanoseconds per day. Additionally, the NTS-2 satellite hosted both NRL's



Timation 4. Launched on June 23, 1977, Navigation Technology Satellite 2 (NTS-2), known also at NRL as Timation 4, was the fourth satellite in NRL's Timation series. (NRL photo 78337.tif)

and the Air Force's ranging signals, that is, side tone ranging and pseudo random noise (PRN) ranging, respectively. The latter included a specially built PRN signal system designed and built by Rockwell International and supplied to NRL for inclusion in NTS-2 that was called the pseudo random noise signal assembly, or PRNSA.⁶⁸

The NRL-developed side tone ranging technique worked by emitting a sequence of radio frequencies that step up from low frequencies to higher ones. Measuring the phase shift in each satellite-emitted frequency with a carrier frequency and precisely comparing them to reference frequencies generated by an oscillator in the receiver determined the range to the satellite. This passive ranging technique was the primary means of determining the receiver's location. The Air Force's ranging approach, PRN, was transmitted as a modulated digital code written in zeros and ones on a single frequency. This code was compared with an identical code in the receiver and the difference measured the range between the satellite and the receiver. The code was also a unique sequence that distinguished each satellite so that a receiver would readily know which signals were coming from which satellite. This meant that a single frequency from each satellite could be used for the ranging as opposed to the multiple frequencies that the Navy's side tone technique required. The digital approach was selected and in time it is what would enable such high degrees of miniaturization that hand-held and even chip-sized GPS receivers would become possible.

In addition to providing a test bed for the two ranging signal systems, NTS-2 hosted other experimental technologies. Again, there were retroreflectors for optical based tracking. There were new solar array designs for testing. It featured a pointing and drive mechanism that would become part of the demonstration satellites Rockwell International was building. There were newly designed nickel-hydrogen batteries for storing power harvested by the solar arrays with a deeper depth of discharge than was possible with the conventional nickel cadmium batteries. Moreover, NTS-2 tested the software and command systems of the GPS ground segment, which provided the tracking, command, and control functions being developed to operate the demonstration constellation of satellites.

After the four experimental satellites (Timation 1 and 2, and NTS-1 and NTS-2), NRL no longer had a role in building the satellites as the NAVSTAR GPS demonstration constellation built by Rockwell was incrementally increased from 6 to 11. Not until the mid-1990s was the 24-satellite configuration declared operational. During the nearly 25-year stretch in which the GPS system was developed, delivered, and deployed, the Transit system was also operated by the Navy. The Naval Space Command maintained the system in an operational status until Transit was retired for navigational purposes at the end of 1996.⁶⁹

The first three Rockwell-built GPS satellites went up in 1978, each carrying three rubidium clocks. The fourth satellite to go up was the first to also include an engineering development model of a cesium clock, which NRL had provided to Rockwell for integration into the satellite. As it turned out, all of the clocks in this initial block of satellites proved to be problematic. The cesium clock that flew on NAVSTAR 4, for one, lasted all of 12 hours, a failure attributed in a subsequent analysis to a faulty power supply.⁷⁰ This led to a top-level reexamination of the program's space-qualified atomic clocks at a meeting of the Defense Systems Acquisition Review Council, which was convened to approve operational deployment of the system. As a result of the subsequent approval, NRL was directed to discontinue working on NTS-3, which was then under construction, and to focus on clock development for the GPS Program. A lasting consequence of that direction was the initiation of the NRL Space Clock Development Program. Beard and his colleagues in the Space Applications Branch (renamed Advanced Space Precision Navigation and Timing Branch) would develop hydrogen maser clocks, refine the cesium clocks in use in the satellites, investigate rubidium clock systems, and continue to evaluate, analyze, and test the performance of the overall system's clocks.⁷¹

Around the same time as the launch of the first GPS satellites, various prototypes of user equipment for the overall system user segment were shipped to Yuma Proving Ground in Arizona for preliminary testing. Among these was a five-channel receiver built by Texas Instruments and a jam-resistant version designed by Rockwell Collins.⁷² In ongoing discussions, Colonel Parkinson and several colleagues convinced the Department of Defense to transfer \$60 million from the Transit program to the

Air Force for the purpose of funding two more GPS satellites. The argument for the shift was that the extra GPS satellites would provide an ability to track Trident missiles during test firings, a capability that was included in plans for an upgrade of the Transit system. Had the plan to increase Transit's tracking capabilities gone through, it could have derailed the work-in-progress NAVSTAR GPS.⁷³

The final system design that emerged out of inter-service NAVSEG deliberations and was incorporated into the GPS program consisted of 24 satellites arranged in three rings of eight satellites each. The final configuration subsequently approved for operational deployment, due to a shift of launch site from Vandenberg in California to Cape Canaveral in Florida, would morph the arrangement into six sets of four satellites at a 55-degree inclination rather than the 63-degree inclination in the original plan. At Cape Canaveral, any inclination over 55 degrees would include flying over land, which posed an unacceptable safety risk.⁷⁴

As with all satellite projects that NRL's space technology cadre worked on since the late 1950s, the Timation and NTS satellites brought out a stream of innovations in satellite design and construction. Al Bartholomew (Roger Easton's deputy), for example, pushed forward the temperature control system for the quartz crystal clocks on the Timation 2 and NTS-1 satellites by making use of newly available thermo-electric devices (TEDs), which would get hotter or cooler on one side depending on which direction the electric current was running through it. "It held the temperature to a milli-degree," Wilhelm said, meaning that the temperature on the crystal in its thermally isolated chambers fluctuated no more than one-thousandth of a degree Celsius.⁷⁵

In his memoir of his years as an NRL space technology engineer who began in 1960, James Winkler recounted that this thermal control innovation was based on "Peltier effect junctions" sandwiched between semiconductor plates to form a TED module. About 10 of these were then stacked between a pair of aluminum plates about the size of big index cards. The modules were extremely fragile, so one of the team members, electrical engineer Jim O'Hara, devised a cushion that was flexible and could absorb shocks even as it also served as a thermal conductor. The clock housing was mounted atop this thermal control assembly. "Pete [Wilhelm] had designed a feedback circuit, based on a complementary differential amplifier that would drive current through the TEDs," Winkler explained. He ran a model of the unit through thermal-vacuum testing, one of the primary tests for proving space worthiness of components and systems. "I was amazed at how well the fragile TEDs stood up to the test program," which included rigorous vibration tests, and proved themselves in orbit aboard NTS-1. Wrote Winkler, "This turned out to be a good application of a unique device and is illustrative of the innovative design capabilities of this organization."⁷⁶

Meanwhile, the entire satellite's temperature needed its own means of stabilization. That took a combination of passive controls, such as vaned structures for passively radiating heat, as well as active means for fine tuning the spacecraft's tem-

perature. Keeping the satellites pointing down was pivotal too. To achieve this attitude control passively for the Timation satellites, the NRL team turned to the gravity gradient stabilization tactic as the means of keeping it pointed in the right direction. In applying this gravity gradient to satellite stabilization, the idea is to include an extendable boom with a mass at the end that is some distance away from the mass of the satellite. “There is a different gravitational attraction on those two masses,” Wilhelm explained. “And what that results in is the satellite would tend to align that boom with the radial vector to the center of the Earth.” As is often the case, a solution begets a problem. The technique required a way, using magnets it turned out, to dampen the pendulum motion that sets in initially as the satellite assumes the general direction along the vertical gravity attraction of the planet.⁷⁷

It was not a perfect technology. A head-shaking illustration of this unfolded with the 1967 launch of Timation 1 along with four other satellites, all associated with the Poppy ELINT program and all of which were equipped with the gravity gradient stabilization systems.⁷⁸ There is an equal chance that a satellite with its boom out will orient either in the desired direction or upside down. That is why the system that Wilhelm and his coworkers at NRL deployed included the capability of retracting the boom and then reeling it out again to initiate motions that can flip the satellite over. As it happened in the 1967 launch, all five of the gravity gradient stabilized satellites initially oriented upside down, an occurrence that had only a 1/32 chance of happening. Wilhelm noted later that the NRL team managed to reorient them all in the proper direction.

There were other challenges in spacecraft stabilization at higher altitudes. The Timation 1 and 2 satellites both went into low Earth orbits where the gravitational effects are stronger than in the higher orbits where the NTS-1, NTS-2, and all subsequent GPS-related satellites would go. It was not known how well the oscillation-tamping magnets on the gravity-gradient booms would work at the higher orbits. What the NRL satellite builders did know is that they would have to use much stronger magnets to dampen the oscillations. That made them worry about whether metal surfaces elsewhere in the satellite would disrupt the magnet’s ability to do its intended job.⁷⁹

Their worries were justified. Sensors on NTS-1 indicated that it was wobbly, even though the directional antennas it used managed to send out emissions of high enough quality to be used to prove the navigation functions. In the more capable operational systems that were to come, this wobbling could threaten the overall system’s reliability and performance and so this wobbling flaw catalyzed innovation. For NTS-2, the magnet-based damping system for quelling the wobbles in gravity gradient booms was taken out of the design and replaced with a more capable stabilization system that was to be used in the Rockwell designed satellites. This stabilization system relied primarily on reaction wheels, or known otherwise as momentum wheels. NRL electrical engineer George Flach had experience with these wheels in the classified

Poppy satellites.⁸⁰

These spinning devices resist a tilting of the spacecraft with respect to the center of the planet and their rate of spin could be sped up or slowed in ways that would correct the satellite's attitude. There is a problem with this type of stabilization. Speeding up and slowing down the wheels elicits a momentum disturbance in the satellite that needs to be corrected. The most direct way to do so is to use thrusters. However, the use of thrusters alters the orbit of the satellite slightly and so can foist motion problems onto the platform as well. The NRL team opted to combine reaction wheels with the gravity gradient technique to open the way to thruster-free stabilization. It took a lot of innovation to make these work, but it was worth it, Wilhelm pointed out, because it reduced the vulnerability to inducing unintentional trajectory changes, a result that would be disastrous for navigational systems in which the satellites' trajectories had to be precisely tracked and predicted.⁸¹ "Every time you fire a thruster, you screw up your tracking system for quite a while," Wilhelm explained. "And we had had plenty of experience with that." The stabilization technique the NRL engineers recommended was to stop using any thrusters once the satellite made it into its final orbit and then to turn stabilization and attitude control over to gravity gradient booms and reaction wheels.⁸²

When the GPS satellite technology was transitioned completely to Rockwell, these lessons learned and many others developed by the many engineers involved helped Rockwell hone the system. As blocks of satellites started to make it into orbit beginning in the late 1970s, the expertise NRL had developed in the atomic clock arena evolved into a dedicated program of technology development for the GPS system, as well as a center with techniques and protocols for evaluating the performance of on-orbit clocks.

As this book was being researched and written, the Space Clock Development Program, which Ronald Beard was overseeing in the Space Applications Branch at NRL, continued this role by monitoring the performance of all the clocks flying in GPS satellites. This group provides this performance data to the operators of the GPS system and alerts the Air Force about specific clocks in the constellation when these begin to show their age with reduced performance or upsets, a situation that could indicate the active clocks in the GPS satellites would need to be switched to one of the other clocks in standby. The motto of the Global Positioning Systems Directorate headquartered at what is now the Los Angeles Air Force Base is displayed on a GPS-themed coffee cup in Beard's office, reminding him of what the system he helps maintain and improve is all about: "Any Time, Any Place, Right Time, Right Place."

After the first block of GPS satellites were built, subsequent blocks began hosting additional payloads, among them sensors for detecting nuclear explosions. That, in itself, rendered the satellites too complex and too heavy for the thrifty Atlas boosters that Wilhelm had pushed for during the demonstration phase of GPS.⁸³ The NASA Space Shuttle originally had been designated as the launch vehicle that would carry

the operational (Block II) satellites into orbit, but the disastrous loss of Challenger in early 1986 demanded an alternative plan. It would be the bigger and more expensive Delta II that became the ferry for taking GPS satellites into orbit. It was the shift to the Space Shuttle and ultimately Delta IIs that moved the launches to Cape Canaveral, Florida. That change entailed the safety-driven shift to an orbital inclination no more than 55 degrees.

Even though the full GPS constellation would not be in place until 1993, the Gulf War in 1990–1991, also known as Operation Desert Storm, provided one of the earliest and most influential publicly revealed military applications of the system.

In a theater of battle where one dune looks like the next, the great sweep of armored forces across the trackless desert was possible only because of GPS instruments on tanks, artillery, and logistics vehicles. In press conferences, General Arnold Schwarzkopf was famously enthusiastic about the pinpoint accuracy achieved by America's newest, GPS-assisted smart weapons. The offensive opened with GPS-guided cruise missiles launched from Navy ships hundreds of miles away in the Persian Gulf directly into Iraqi air defenses and installations, among other military assets.⁸⁴

From there forward, GPS has been present in the military in myriad ways every day. One of the more suspenseful uses of GPS took place on June 6, 1995. At 2:08 in the morning, American F-16 pilot Captain Scott F. O'Grady, who had been downed four days earlier over Serb-controlled territory during a no-fly-zone operation, finally risked radio communication with his comrades as he hid from Serbian forces. Using a GPS receiver hidden inside his life vest, O'Grady was able to determine his own longitude, latitude, and altitude (although he was on the ground) to within a few hundred feet. With that intelligence, a Tactical Recovery of Aircraft Personnel team of the 24th Marine Expeditionary Unit was able to extract O'Grady from behind enemy lines a mere four hours after F-16 flyers first picked up their comrade's distress call.⁸⁵

Lucky for O'Grady, his adversaries were not jamming the GPS signals that saved his life. From the early phases of GPS, even during the Labor Day meeting at the Pentagon back in 1973, everyone involved in the program had been concerned about electronic jamming, spoofing, and other tactics that enemies could deploy to deny the U.S. and its allies use of GPS technology. Because of GPS's weak signals, jamming is fairly easy, notes Wilhelm, adding by way of example that it was a problem in Afghanistan.⁸⁶

Although it is possible to thwart a would-be jammer by increasing the transmission power of the satellites, the jammer, working more conveniently with ground-based electronic countermeasures, always can counter that boost in signal power with yet more jamming power, or get in closer to the receivers he is hoping to jam. As often has been the case with military developments that would be valuable to both services, the Air Force and the Navy have come up with differing approaches to reducing vulnerability to jamming, according to Wilhelm.

In the next phase of the program called GPS 3, Wilhelm noted in 2014, the Air Force was looking toward a system with higher transmission power, and other modifications that would decrease the vulnerability of the signals. One advance centers on changes in the content and modulation of the signals. As an interim solution to the signal-vulnerability problem in the period before GPS 3 is fully implemented, NRL pursued another option: High Integrity GPS (HIGPS). This project aimed to exploit a constellation of an already on-orbit communication satellite system, called Iridium.

As communication satellites, these were designed with high-power transmitters and were in low-altitude orbits. Because they were closer to the receivers on the ground, the signal from these satellites can be higher power than those from GPS satellites. By using these satellites to transmit synchronizing information about the GPS clocks and signal-acquisition data to receivers, it becomes possible to augment the weaker GPS signals with this information from the higher power Iridium signals.

“It’s a system that is already up there,” noted Wilhelm. “You don’t need to put up any more satellites.” In the field, ground stations of an HIGPS would be capable of receiving downlinks from both GPS and Iridium satellites. These data and corrections for any clock-based differences in the system would then be transmitted back up through the Iridium satellites as a communication message to the users’ GPS receivers. NRL has taken the first steps with laboratory demonstrations indicating that soldiers with receivers rendered HIGPS-ready with hardware and software plug-ins would effectively hear HIGPS signals as though they were a thousand times more intense than from a GPS only.⁸⁷ In 2014, the Office of the Director of Defense Research and Engineering (DDR&E), which resides within the Office of the Secretary of Defense, was evaluating the options for a jam-resistant GPS upgrade and analyzing the budgetary consequences of each.⁸⁸

Just before Christmas in 2018, the Air Force did take a step toward a GPS upgrade with the successful launch of the first satellite of the block with higher power transmitters designated GPS 3. If this block of satellites performs as planned as it becomes integrated into the full constellation of GPS satellites in the coming years, the upgraded GPS system will deliver three times more accurate time and position information and more powerful and less-jammable signals.

While GPS’s most sophisticated abilities remain within the military domain, its publicly available features have been put to use in all kinds of ways. When the Department of Defense opened GPS technology for commercial development, an army of innovators got going and a commercial industry was born. The most visible early result of this was GPS-based navigation systems in fleets of cars and trucks, an innovation founded on the marriage of GPS with maps, geographical information systems (GIS technology), and route calculation programs. Trucking companies track their fleets and plan routes using GPS, as do sea-based shipping companies. Pilots, cartographers, city planners, wilderness hikers, construction engineers, road builders, telecommunications companies, and automobile makers are among the millions

who rely on GPS for what they do or in devices that help them sell their wares. Two decades after the capability was first envisioned, estimates of the numbers of military and civilian users worldwide of GPS would soar into the many tens of millions.⁸⁹

Remarked Wilhelm: “When you think about the fact that the [GPS receiver in your car] can not only tell you where you are, but it has figured out the most efficient route ... and as you get near the corner it warns you okay, you’re going to turn in about 400 feet ... that’s a pretty powerful app there.”⁹⁰

Cell phone technology, most notably the miniaturization of electronic and radio frequency components, also was pivotal for hand-held GPS technology. The addition of GPS functions to cell phones opened up a world of geolocation-based applications that have become among the most popular features of smart phones.

Although the Global Positioning System’s most familiar missions are navigation and geolocation, its mission as a versatile orbiting time standard for ultraprecise synchronization of clocks in communications, intelligence, cryptological, and other systems is just as vital in the commercial world as it is in defense and security circles. As indicated earlier, this mission goes by names such as “time transfer” and “time dissemination.” For example, to build anti-jamming capability in communications and other systems by, say, rapidly hopping between frequencies or condensing information in quick signal bursts, requires precision timing between emitters and receivers.

In the arena of ocean surveillance, precision timing is essential for pinpointing the location of, say, ocean-going electromagnetic emissions. GPS’s time dissemination mission is central to much of the civilian infrastructure as well. The precise synchronization of clocks in widely spaced components of power grids, cell phone systems, and the Internet is what makes it possible to manage, respectively, the instant-to-instant flow of electricity, the tower-to-tower handoffs of millions of specific cell phone conversations, and the distribution and reassembling of vast numbers of data packets that underlie the working of the Internet.

“GPS is considered the primary means of time dissemination, because of its ability to serve passive users, its continuous worldwide coverage, its built-in survivability, its accuracy, and its simultaneous position solution that is often needed by precisely timed systems,” Beard and several colleagues wrote in a review of GPS clock technology.⁹¹

Even in 1992, well before GPS became such a widespread motif of the technological landscape, the National Aeronautic Association (NAA) recognized the principals of the GPS development team—NRL, the U.S. Air Force, Aerospace Corporation, Rockwell International Corporation, and IBM Federal Systems Company—by awarding them its 1992 Robert J. Collier Trophy. This award is presented annually, in NAA’s words, “for the greatest achievement in aeronautics or astronautics in America, with respect to improving the performance, efficiency, or safety of air or space vehicles, the value of which has been thoroughly demonstrated by actual use during the preceding year.”⁹² The NAA cited the GPS team for “the most significant development for safe

and efficient navigation and surveillance of air and spacecraft since the introduction of radio navigation 50 years ago.” NRL’s copy of the Collier Trophy has been located for maximum visibility in the lobby of Building 43, the main administrative building where the lab’s leadership has its offices.

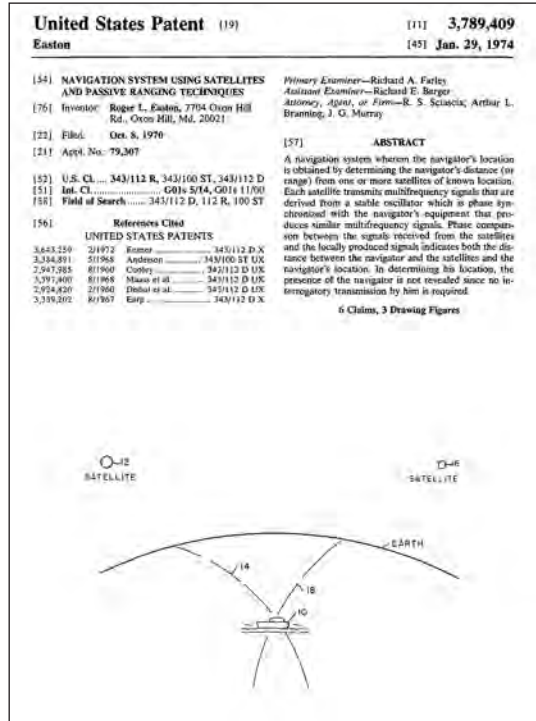
Roger Easton received many accolades for his seminal role in the origin, engineering, and implementation of the GPS program. In 2005, for one, he was honored by President George W. Bush with the 2004 National Medal of Technology. The citation states that Easton received the medal for “his invention of the Minitrack satellite tracking system used to track Vanguard satellites and determine orbits; his development of the Naval Space Surveillance System ...; his invention of a ‘Navigation System Using Satellites and Passive Ranging Techniques’ and his subsequent development of Time Navigation and Navigation Technology Satellites that formed the technological basis for modern GPS.”⁹³ In 2010, Easton, who retired from NRL in 1980 just as the first operational GPS satellites were making it into orbit, was inducted into the National Inventors Hall of Fame.⁹⁴ He died in 2014.



The Collier Trophy. Along with partners in the Air Force, Rockwell International Corporation, Aerospace Corporation, and IBM, NRL shared the glory on May 4, 1993, of receiving the Collier Trophy, among the most prestigious accolades in the aerospace community, for its pioneering role in the conception and development work that led to the world- changing Global Positioning System (GPS). Shown are Captain Paul Gaffney, NRL’s Commanding Officer; Roger Easton, with the Collier trophy; Dr. Timothy Coffey, NRL’s Director of Research; Pete Wilhelm, Director of NRL’s Naval Center for Space Technology; and Rear Admiral William Miller, Chief of Naval Research. The trophy resides in a display case in the lobby of Building 43 on NRL’s campus. (NRL photo 93-000087(25).jpg)



GPS Pioneer. Roger Easton, one of NRL's most celebrated engineers for his role in the invention of what became known across the world as the Global Positioning System, shares remarks at his induction into the National Inventors Hall of Fame. The citation noted Patent No. 3,789,409, associated with the Timation Satellite Navigation System, a precursor to GPS. (NRL photos ND2_2287.jpg and 25-13r_GPS_USPat_3789409_2320x3408)



¹ Bradford W. Parkinson, Thomas Stansell, Ronald Beard, and Konstantine Gromov, “A History of Satellite Navigation,” *Navigation* 42, no. 1 (Spring 1995): 109–164.

² Applied Research Laboratory, The Pennsylvania State University (ed.), *From the Sea to the Stars: A Chronicle of the U.S. Navy's Space and Space-related Activities, 1944–2009* (revised and updated edition, 2010), p. 42.

³ Roger Easton, oral history conducted by David van Keuren, March 8, 1996.

⁴ Roger Easton, oral history, 1996, p. 22.

⁵ Peter Wilhelm, oral history, February 13, 2012.

⁶ Roger Easton, oral history, 1996, p. 35.

⁷ Wilhelm, oral history, February 13, 2012.

⁸ Tina Thomson (ed.), *Space Log, 1957–1987* (Redondo Beach, CA: TRW, 1988).

⁹ Peter Wilhelm, oral history conducted by NRL Historian Leo Slater, August 7, 2009.

¹⁰ Wilhelm, oral history, August 7, 2009.

¹¹ Light traveling at 186,000 miles per second travels 186 miles in one thousandth of a second.

¹² Roger Easton, oral history, 1996, p. 56.

¹³ Roger Easton, oral history, 1996, p. 56.

¹⁴ Wilhelm, oral history, February 13, 2012, p. 14.

¹⁵ Ronald Beard, personal communication, April 2014.

¹⁶ Peter Wilhelm, oral history about GPS history, February 14, 2012, p. 68.

¹⁷ C.A. Bartholomew, “Quartz Crystal Oscillator Development for Timation” NRL Report 7478 (Washington, DC: Naval Research Laboratory, October 25, 1972).

¹⁸ Robert L. Whitlock and Thomas B. McCaskill, “NRL GPS Bibliography: An Annotated Bibliography of the Origin and Development of the Global Positioning System at the Naval Research Laboratory,” NRL/MR/1001-09-8988 (Washington, DC: Naval Research Laboratory, June 3, 2009), pp. 9 and 84.

- ¹⁹ Wilhelm, oral history, February 13, 2012, pp. 17–18.
- ²⁰ Roger Easton, oral history, 1996, p. 58.
- ²¹ Roger Easton, oral history, 1996, p. 60.
- ²² Roger Easton, oral history, 1996, p. 66.
- ²³ Wilhelm, oral history, August 7, 2009.
- ²⁴ <http://www.nps.gov/joer/historyculture/index.htm>.
- ²⁵ T.B. McCaskill and R.R. Whitlock, “40th Anniversary of Historic NRL Navigation Demonstration,” *Abstracts*, Naval Research Laboratory, pp. 4–7.
- ²⁶ McCaskill and Whitlock, “40th Anniversary.”
- ²⁷ McCaskill and Whitlock, “40th Anniversary.”
- ²⁸ McCaskill and Whitlock, “40th Anniversary.”
- ²⁹ Ronald Beard, personal communication, April 2014.
- ³⁰ The Naval Weapons Laboratory was renamed in 1974 as the Naval Surface Weapons Center and in around 1990 as the Naval Surface Warfare Center.
- ³¹ Parkinson et al., “A History of Satellite Navigation,” p. 125.
- ³² Roger Easton, oral history, 1996, p. 77.
- ³³ Roger Easton, oral history, 1996, p. 77.
- ³⁴ Ronald Beard, personal communication, April 2014.
- ³⁵ Wilhelm, oral history, February 14, 2012, p. 69.
- ³⁶ Wilhelm, oral history, February 14, 2012, p. 71.
- ³⁷ Parkinson et al., “A History of Satellite Navigation,” p. 126.
- ³⁸ Roger Easton, oral history, 1996, pp. 83–84.
- ³⁹ Wilhelm, oral history, February 13, 2012, pp. 39–40.
- ⁴⁰ Wilhelm, oral history, February 13, 2012, pp. 40–42.
- ⁴¹ Roger Easton, oral history, 1996, p. 87.
- ⁴² Wilhelm, oral history, February 13, 2012, p. 43.
- ⁴³ Roger Easton, oral history, 1996, p. 85.
- ⁴⁴ Parkinson et al., “A History of Satellite Navigation,” p. 126.
- ⁴⁵ *From the Sea to the Stars*, p. 90.
- ⁴⁶ Parkinson et al., “A History of Satellite Navigation,” p. 136.
- ⁴⁷ Ronald Beard, interview with author, March 12, 2012.
- ⁴⁸ Parkinson et al., “A History of Satellite Navigation,” pp. 136–137.
- ⁴⁹ Richard Easton, *GPS Declassified: From Smart Bombs to Smartphones* (Potomac Books, 2013), pp. 65–70.
- ⁵⁰ Roger Easton, oral history, 1996, pp. 71–72, 89.
- ⁵¹ Wilhelm, oral history, February 13, 2012, p. 43.
- ⁵² *From the Sea to the Stars*, p. 91. A footnote points out that there remains some controversy on whether NRL or the Air Force deserves more credit for the overall design of the GPS system.
- ⁵³ Parkinson et al., “A History of Satellite Navigation,” p. 137.
- ⁵⁴ *From the Sea to the Stars*, pp. 90–92; Ronald Beard, personal communication, April 2014.
- ⁵⁵ Wilhelm, oral history, February 13, 2012, p. 24.
- ⁵⁶ Lee Hammarstrom, draft of memoir shared with author, November 2013.
- ⁵⁷ Wilhelm, oral history, February 13, 2012, p. 25.
- ⁵⁸ R.L. Beard, J. Murray, and J.D. White, “GPS Clock Technology and the Navy PTTI Programs at the U.S. Naval Research Laboratory,” in Proceedings of the 18th Annual Precise Time and Time Interval (PTTI) Applications and Planning Meeting, 2–4 December 1986, Washington, DC, 1987.
- ⁵⁹ Roger Easton, oral history, 1996, p. 104; Ronald Beard pointed out in a manuscript review that the number of Efratou units NRL purchased was six, rather than the two Easton reported during the oral interview.
- ⁶⁰ Wilhelm, oral history, February 13, 2012, pp. 30–31.
- ⁶¹ Wilhelm, oral history, February 13, 2012, pp. 26–27.

- ⁶² Wilhelm, oral history, February 13, 2012, p. 25.
- ⁶³ Wilhelm, oral history, February 13, 2012, p. 30.
- ⁶⁴ Wilhelm, oral history, February 13, 2012, p. 31.
- ⁶⁵ Wilhelm, oral history, February 13, 2012, p. 32.
- ⁶⁶ Wilhelm, oral history, February 13, 2012, pp. 32–34.
- ⁶⁷ Parkinson et al., “A History of Satellite Navigation,” p. 130.
- ⁶⁸ Wilhelm, oral history, February 13, 2012, p. 56.
- ⁶⁹ *From the Sea to the Stars*, p. 121.
- ⁷⁰ Natarajan D. Bhaskar et al., “A Historical Review of Atomic Frequency Standards Used in Space Systems,” Proceedings of the 1996 IEEE International Frequency Control Symposium, pp. 24–32.
- ⁷¹ Parkinson et al., “A History of Satellite Navigation,” p. 134.
- ⁷² Parkinson et al., pp. 138–139.
- ⁷³ Parkinson et al., p. 139.
- ⁷⁴ Parkinson et al., pp. 141–143.
- ⁷⁵ Wilhelm, oral history, February 13, 2012, p. 49.
- ⁷⁶ James Winkler, private memoir shared with author, 2012.
- ⁷⁷ Wilhelm, oral history, February 13, 2012, p. 50.
- ⁷⁸ The same launch included yet two more NRL-built satellites, these for calibrating the NAVSPASUR system.
- ⁷⁹ Wilhelm, oral history, February 13, 2012, pp. 50–53.
- ⁸⁰ George Flach, interview with Art Collier, January 29, 2009.
- ⁸¹ Wilhelm, oral history, February 13, 2012, pp. 53–54.
- ⁸² Wilhelm, oral history, February 13, 2012, pp. 53–54.
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- ⁸⁴ D. Bundy, “Time, Navigation, and Global Positioning: NRL’s Research Aids Desert Storm Operations,” *Labstracts*, Naval Research Laboratory, September 23, 1991, pp. 1, 4, 5.
- ⁸⁵ See, for example, William Menner, “The Navy’s Tactical Aircraft Strike Planning Process,” Johns Hopkins APL Technical Digest, vol. 18, no. 1 (1997).
- ⁸⁶ Wilhelm, oral history, February 13, 2012, pp. 62–63.
- ⁸⁷ Wilhelm, oral history, February 13, 2012, pp. 63–65.
- ⁸⁸ Chris Dwyer, personal communication, 2013.
- ⁸⁹ See, for example, <http://www.numberof.net/number-of-gps-users> and <http://www.fos.org/spp/military/program/nav/transit.htm>.
- ⁹⁰ Wilhelm, oral history, February 13, 2012, p. 41.
- ⁹¹ Beard et al., “GPS Clock Technology,” 1987, pp. 46–47.
- ⁹² <http://naa.aero/html/awards/index.cfm?cmsid=57>.
- ⁹³ <http://www.nrl.navy.mil/media/news-releases/2005/president-announces-roger-easton-recipient-of-national-medal-of-technology>.
- ⁹⁴ http://www.invent.org/hall_of_fame/410.html.

CUTTING THE CORD AND THE BIRTH OF THE NAVAL CENTER FOR SPACE TECHNOLOGY

As the NRL master builders of ELINT satellites were assembling what would be the last block of Poppy satellites, which were the centerpieces of the National Reconnaissance Office's (NRO) Program C, while also working on the test phase satellites of the future Global Positioning System (GPS), they were unwittingly on their final stretch as the satellite production house that they had been since the days of Project Vanguard at the very beginning of the Space Age.

Unlike NRO's three other lettered reconnaissance programs (A, B, and D), Program C had only one component to it and that was Poppy, the follow-on series of satellites to those in the GRAB program. The program fell within the Navy Space Projects Office (also designated PME 106) of the Naval Electronic Systems Command (NAVALEX), part of the Naval Material Command (NAVMAT). "They managed it, they executed it, and they developed the technology" for the GRAB and Poppy missions, said Tom Betterton, referring to the NRL satellite team under the leadership of Pete Wilhelm.¹ In 1979, Betterton took over as manager of PME 106-5, NAVALEX's Special Projects Office² within the Navy Space Projects Office.

"I got a call from Rear Admiral Bob Geiger," in the late-1974 or early-1975 time frame, said Betterton, recounting how he eventually ended up working with NRL's ELINT satellite makers. He had a background in aeronautics and astronautics and so had gotten onto Navy leadership's radar screen as a candidate for space-related jobs. "Geiger said, 'Would you like to come to the Navy Space Projects Office,'" which the Rear Admiral had been heading. When Betterton met with Geiger to hear about the job, he was ushered into a broom closet in the building where the interview unfolded. "Literally in a closet," Betterton stressed. At that point, he did not yet have the security clearances required to enter the SPO, the Special Projects Office, which was located behind cypher lock doors.³

"Welcome to the Navy Space Projects Office," Geiger said to Betterton in the cramped closet. "You would really like it," Geiger reassured Betterton.

"What are we doing?" asked Betterton.

"Well, we can't tell you," said Geiger. "But you will really enjoy it."

It was a classic Catch-22. Without having the proper clearances, Geiger couldn't tell Betterton much about the program he was supposed to join. But without taking the job, Betterton wouldn't get the clearances. "At that point in time, this was deep

black,” Betterton noted. “The existence of NRO was not acknowledged, not admitted, nobody even mentioned it, nobody wore uniforms.”



NRO Boss. Rear Admiral Tom Betterton, shown here in 1988, was head of the Special Projects Office, a component of the Navy Space Projects Office, from 1979 to 1986. (NRL photo Betterton1988.1.jpg)

There was change afoot in the management of NRO programs. The first four directors of Program C, from 1962 to 1971, had all been the Directors of Naval Intelligence. It was a reflection of just how much in Navy control the program was. Up until that point, there was no NRO-anchored SPO; the program was Navy managed, Navy executed, and Navy made. But when Betterton joined Program C, the NRO was on its way to taking on a different point of view. Rather than being a Navy satellite program (whose roots preceded by three years the establishment of the NRO in 1961) that happened to be housed within the NRO context, Program C was to become an NRO program that happened to have been a Navy-anchored initiative.

“NRL essentially was a sole source provider to Program C,” said Betterton, by which he meant the lab—having invented and continuously improved the GRAB and Poppy spacecraft over the years—was the only organization that Program C could rely on to affordably build additional one-of-a-kind ELINT satellites.⁴ But after Betterton took over as SPO director in 1979, he also was tasked by his NRO bosses to change things in the program and to make decisions based on business parameters, not just technical ones. For example, if an aerospace contractor could build perfectly capable satellites for Program C instead of NRL, then the NRO should shift the satellite-crafting work away from NRL to the contractor.

This was a drastic move. The formation in 1974 of the SPO was, from NRL’s point of view, foisted upon the lab, said Betterton. NRL treasured its get-it-done culture, and when the SPO came its way, the lab’s satellite cadre was getting it done for Poppy and the next GPS satellite, also known as the first Navigation Technology Satellite (NTS-1). “They would not be fans of any additional management layers,” Betterton observed.

Yet that managerial layer non grata is just where Betterton had landed. The SPO director at the time explained to Betterton that his job would be to manage the technology development for, in Betterton’s words, “the space segment, the hardware,” that

NRL had been developing and building for Poppy. The SPO Director added, “That is what you will be doing, but let me tell you, those sons of bitches at NRL, they can’t be managed.” Upon establishing the SPO, it didn’t take long for the friction to begin and build. “After a couple of months, there were personality conflicts galore—from the original establishment of the SPO—to the point where [SPO and NRL personnel] would not talk to each other, even if there happened to be an occasional social function,” Betterton recalled much later, referring to what he heard from others about the environment he was entering.⁵

After Betterton took the baton as SPO director, he managed to break through the little local cold war by, in part, making a phone call to Pete Wilhelm. Wilhelm was in charge of the Satellite Techniques Branch, which was soon to be designated as the Spacecraft Technology Center (Code 7040) where he would report directly to the Associate Director of Research for Space Science and Technology, Dr. Herbert Rabin. Betterton introduced himself to Wilhelm and offered to come over to his office to meet and talk about the program they now were partnering on. There was silence on the other end, Betterton said. “You are going to come to my office?” Betterton recalled Wilhelm asking with incredulity. Such a visit apparently had never happened since the SPO’s establishment several years earlier. With the ice now broken, Wilhelm and his space technology comrades no longer necessarily looked upon the SPO as the enemy, said Betterton.

But Betterton had some bad news to deliver. An upper-level NRO decision had been made that NRL would henceforth no longer be involved in the production of satellites for Program C as they had been since Poppy’s predecessor program, GRAB, had begun in the late 1950s. Betterton’s orders were to transition the technology invented at NRL to industry for production. It was a huge blow to NRL, Betterton noted, because it meant “if there was going to be any production, or any follow-on satellites to the Poppy series, or any evolution of this technology, it basically would be vested in industry.”⁶

But it was fated to be so. “That was an interesting time to try and meld a philosophy and way of doing business—which was deeply rooted in NRL and Pete’s guys—with the industry assuming responsibility for bringing this technology to fruition and making it work operationally,” Betterton said. “We all learned a lot in the initial transition,” which unfolded in the late 1970s and early 1980s. One hard lesson was that transitioning a technology that already had been developed and proven by one group of innovators to another group is akin to forcefully removing someone’s child from its original household and bringing it to someone else’s house to grow up. The better way to go, both Betterton and the NRL satellite builders learned from the pains of that first transition, was to have both parties of the transition work together from the beginning in a kind of co-parenting context. A primary practice from then on was for the NRL experts to design a prototype payload and to work with industry partners who would move from the prototype to production satellites.⁷

This was a time in the 1970s when the Soviet Union's naval forces were evolving a "blue water" threat, replete with anti-ship missiles and submarines with ICBMs. "So the Navy was quite interested in ship tracking, what we call today Maritime Domain Awareness," Betterton explained. Photoreconnaissance was limited in this context to mostly ports where, say, submarines would be docked and visible. "How do you know where the bad guys are and what their capabilities are in the open ocean" was the more important and challenging question to answer, Betterton noted, adding that "this is where SIGINT may have come into play." The difference from the GRAB and Poppy era, however, was that the primary concern for the Navy shifted from the strategic national intelligence perspective—with specific targets that included the Soviet anti-missile and anti-aircraft radar systems—to the support of military operations. The focus became, in Betterton's words, "the tactical applications of space capability."⁸

For the NRL space technologists, it was a shift of conceptual emphasis that would bring with it a massive realignment of its research and development portfolio. Intelligence-gathering satellites remained in the picture, says Betterton, but Wilhelm's cadre had to begin to recognize "that the manipulation of the data that is collected into information, and the distribution of it, and the use of it, and the putting of it together, is much more important" than the satellites themselves. It was this recognition that led one of the contractors that Betterton had worked with as he managed Program C to wryly refer to the satellites as "orbiting peripherals."⁹ Perhaps even more jarring and novel to the NRL space technology cadre was that it took them out of the context of being a single-source provider as it had been during the prior two decades for NRO's Program C. And because NRL was a so-called "working capital funded lab" at which work is done primarily for sponsors who want the work to be done enough that they are willing to pay for it out of their own budgets, this shift made the NRL space cadre vulnerable to a loss of funding to competitors.¹⁰

This new context meant, Betterton said rather colorfully, that "this good old daddy rabbit SPO [that is, NRO] that was sending you guys a lot of money every year is no longer there."¹¹ The NRL/NRO connection would never go away, not by a long shot, but it changed dramatically as the Poppy program was fading in the 1970s. Rather than building hardware, Betterton observed, the lab's "involvement with the NRO at that point in time became really more of a support role" with specific tasks including assistance in setting requirements for new systems, in acquiring them in good and working shape from contractors, and in developing some high-risk technology components and systems. Henceforth, beginning in the late 1980s, some of the satellite wizards under Wilhelm's wing at NRL would be detailed intermittently to the NRO where they would review bids and proposals from industrial contractors and help NRO make sure contractors delivered on their promises. Many long-time staff in NRL's Code 8000, which was designated the locus of the Navy's space technology expertise in 1986, have done tours (sometimes years-long details) at NRO headquarters at some point in their careers, helping the NRO make good decisions as it carries

out its own responsibility of overseeing the nation's space-based intelligence assets and capabilities. "This was quite a change from the 70s, and 80s, even before that, when [NRL was] actually building, launching, and operating technologies," Betterton observed.

In the same years that the Poppy program was winding down, the long-standing collaboration between NRL's space scientists and the lab's space technology engineers continued to be productive. Ever since June 1960, when the GRAB 1 pioneering ELINT payload shared a spherical shell with the SOLRAD 1 scientific payload for measuring solar radiation, the two groups at NRL had been closely allied. Various combinations of scientists and engineers worked together on a series of SOLRAD payloads, ending with SOLRAD 11, which also was known as SOLRAD Hi because of the unprecedented altitude of its pair of satellites after a launch on March 14, 1976. There were many successes, and some failures, along the way. The scientific payoffs centered on the characterization and monitoring of X-rays and ultraviolet radiation from the sun, the way this radiation interacted with the atmosphere (most notably the ionosphere), and how those interactions affected both militarily relevant capabilities such as long-distance, high-frequency communication, and civilian space program concerns such as radiation exposure by NASA's astronauts.

Barring the failure of a launch vehicle to ferry the payloads to orbit, as was the case for SOLRAD 2 (November 30, 1960), SOLRAD 4A (January 24, 1962), and SOLRAD 4B (April 26, 1962), virtually nothing could stop NRL's space technology team from solving whatever problem might crop up. Mechanical engineer James Winkler recalled a harrowing example with SOLRAD 10 in the summer of 1971 involving the malfunction during a prelaunch test of a pyrotechnic device for releasing the satellite's quartet of solar cell paddles after the spacecraft separated from the booster.¹² "I had written a procedure to check out the satellite configuration prior to mounting it on the Scout vehicle," Winkler recalled, referring to the booster. "We had not had time to run this procedure back at the lab," he continued, adding that he and the SOLRAD 10 spacecraft manager, Jim O'Haro, then agreed to run the test in the field at the launch site at Wallops Island, Virginia. Just hours before they were slated to transport the payload to the launch pad so that it could be installed in the rocket, the two inserted the "turn-on-plug" that Winkler's procedure called for. That is when the unthinkable happened. "The pyro-technic device fired and released the four paddles which had been configured for the flight!" said Winkler.

With no time for denial over what just had happened, Winkler quickly diagnosed the problem. "I had forgotten to call for depressing the separation switches [into the off position] in the procedure," he recounted. At first, he figured a colleague, Bob Beal, would have brought some spare ordnance devices, but it turns out he had not. So Beal called another NRL colleague, Skip Shepherd, who was president of a private flying club that Winkler and several others were a part of, and asked him to fly down from NRL in Washington, DC, to Wallops Island with replacement devices. "An hour

or two later, he made a beautiful landing on the beach, not far from our building,” said Winkler. “By that time, everyone had gone to dinner—except me. Skip and I took the devices and wired them up to the [payload] harness ... we met our scheduled mating time with the [launch vehicle].”



Problem Solver. Mechanical engineer James Winkler conducts tests on the SOLRAD 9 payload prior to its launch in March 1969. (NRL photo Jim Winkler Solrad IX 001)

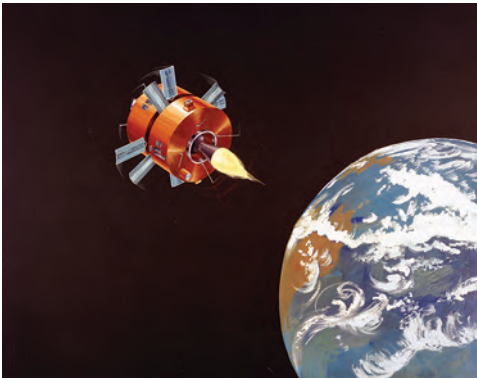
In the following years, Winkler was a part of the team—led by Ernest Peterkin, a retired naval officer (Captain) who served as NRL’s overall Project Manager for the mission—that was working on SOLRAD 11, the last mission in the 16-year-long solar science series. It featured two instrument-laden satellites that would be placed in high orbits of 65,000 nautical miles and arranged on opposite sides of the planet. It was one of the largest and most complex missions the lab had ever worked on. “It took two months to completely test the satellites, build up the SOLRAD Transfer System (STS), integrate the STS on the launch vehicle and finally launch” with a Titan IIIC booster, said Winkler, SOLRAD 11’s Spacecraft Project Manager. The STS, for which Beal worked out the initial design, included two puck-shaped satellites along with an apogee kick motor (AKM) and a perigee kick motor (PKM), which were the solid propellant rockets that would usher the satellites into their respective high-altitude orbits.

Winkler and the rest of the NRL team had to work with several partner organizations, including Lincoln Laboratories, which was supplying a pair of communications satellites (powered by small radio-isotope-fueled power generators); TRW Corporation, which was responsible for the structure that would support all the payloads; and the Air Force Space Test Program, whose managers were in charge of overall integration of the satellite and booster and the launch itself. Each satellite hosted 25 experiments, most of them designed and prepared by NRL’s own space scientists under the supervision of Robert Kreplin and Dr. Donald Horan and with pivotal help from computer specialist Albert J. Martin, who, Winkler noted, “designed all the software for processing the experimental data as well as the software to establish the orbit and track the satellites.”¹³

The experiments ranged widely and included measuring electromagnetic and charged particle emissions from the sun, Earth's own auroral and stellar X-ray emissions, extreme ultraviolet emissions, X-ray and charged particle emissions from both terrestrial and interplanetary sources, and highly energetic gamma-ray bursts.¹⁴ NRL's space scientists became leaders in the study of these phenomena.

The launch on March 15, 1976, was a huge success and Winkler was among a small NRL team that left the Cape Canaveral launch site via Learjet so they could be at the primary ground station in Blossom Point, Maryland, where they then could control the operation of the SOLRAD 11 payloads after they separated from the booster. A lengthy series of procedures, including telemetry-based health checks on the spacecraft, deployment of the solar cell panels, activation of reaction wheels and other systems to make sure the satellites would have the right attitude and its solar radiation sensors would be pointing at the sun, went flawlessly. Same went for the “big maneuver” in the evening—the firing of the perigee kick motor to usher the stacked 5-foot pucks to an elliptical orbit with high and low points at 65,000 and 19,296 nautical miles, respectively. A week later, the team executed the next big maneuver—activating the apogee kick motor to circularize the satellites' orbit at 65,000 nautical miles.

It would take another complex sequence of procedures to separate the satellites and position them on opposite sides of the world, but it all went on with hardly a bump. SOLRAD 11B transmitted experimental data until the end of 1976 and its sister, SOLRAD 11A, continued on sporadically until the following July.



Solrad Hi. Artist's rendition of the two-payload SOLRAD 11 mission at a point when the perigee kick motor is firing to bring the payloads to a higher orbit. Also known as SOLRAD Hi, the payloads were finessed into positions in high orbits on opposite sides of the planet where they measured solar radiation. (Source: *Solrad XI STS PKM Firing (77311(2).jpg)*)

The lab's space technology engineers and space scientists would never work together quite as closely, or at least not as consistently, after the SOLRAD series ended. During the several years of the SOLRAD 11 mission, different but sometimes overlapping constellations of NRL's space technology contingent were working to prepare NTS-2 (the fourth satellite in the initial phase of the GPS technology development) and helping push forward then-classified technologies in the GRAB and Poppy lineage, such as the Multiple Satellite Dispenser (MSD), with industry partners that were building the satellites associated with these programs.



Orange Team. The SOLRAD Hi launch team, sporting orange jackets, pose together in March 1976 at the launch site at Cape Canaveral, Florida. (NRL photo 78035(62).jpg)

Captain Art Collier, who in 1986 succeeded Betterton as the SPO director, pointed out that a key role NRL's satellite engineers played in this regard was "to develop and then transition to the industrial partners new, high risk payloads for follow-on satellites. One such subsystem was deemed so high risk by the contractor that we (the SPO) could not negotiate an affordable contract to develop it. The lab successfully developed the capability with the contractor looking over their shoulders, at a reasonable cost, and smoothly transitioned it."¹⁵

For the country and for the NRO, these surely were important roles for NRL's space technology experts to play. From an institutional psychology perspective, however, merely playing a support role for the NRO, as important as that was for national security, would not suffice for the NRL satellite builders, not unless they were willing to abandon the Space Age culture whose very formation they had been such a central part of. The risk for this pioneering space technology team of losing its place in the satellite-building game only intensified as both the SOLRAD series and the NTS-2 missions were coming to a close. "Most of those guys still wanted to build hardware," Betterton pointed out. And it was to everyone's benefit if they did at least some of that. "If they didn't continue to build hardware, their value as technical advisors and overseers would diminish over time," Collier added.¹⁶

To stay in the game the way they wanted to, Wilhelm and his space technology staff either (1) needed to hook up with new sponsors who needed the kinds of satellites and satellite technology they always had designed, built, and operated, or (2) needed to embrace the double-edged quip that the satellites had become "orbiting peripherals" as an enormous opportunity to remake themselves. If the satellites merely were at an edge of an overall system that collected, processed, packaged, distributed,

interpreted, and acted on intelligence data and information, then the NRL satellite team could become go-to guys for all of that too.

Wilhelm and his top lieutenants—Bob Eisenhauer, Bob Beal, and Lee Hammarstrom—would lead the team down both pathways.

Most emblematic of the remaking of NRL's space technology operation once it handed off its satellite building practice to industry partners was its emergence in 1986 from its place within the Space Systems Division (Code 7700) into its very own triple-zero code—8000—known in words as the Naval Center for Space Technology (NCST). In part, this reflected a trend of scientific organization, particularly in Academe, to expand from traditional “stovepiped” departments into “centers of excellence” that brought together a diversity of backgrounds, departmental affiliations, skills sets, and know-how for doing multidisciplinary research or solving complex technology challenges. With its assemblage of rocketry, fuel chemistry, advanced materials, sensor design, electronics, orbital analysis, tracking systems, command and control, communications, data handling and processing, and systems engineering and integration, to name some of its aspects, space technology always had been a pursuit anchored in just about every science and technology humanity had yet devised and mastered. And so, consolidating NRL's space technology expertise into a Naval Center for Space Technology made sense. At the same time, the lab had already been assembling whatever skills it needed for any particular space technology mission or task, so shifting all that under NCST felt to many like little more than a name change.

As Betterton saw it from his role both as the head of NRO Program C, which had been managing NRL's role in Poppy and follow-on ELINT systems, and his other job as Assistant Commander for Space Technology in the Space and Naval Warfare Systems Command (SPAWAR), the formation of NCST helped prevent a diffusion and evaporation of the hard-won space technology skill set at NRL even as tidal forces at higher levels of the military and government might have otherwise caused the disintegration of this national asset.

“My thought was to get a structure that looked at the technology interest, the science, any space involvement of the Navy—which by definition was going to be relatively small and not real well funded” any more, said Betterton. “And if [that structure] were also to continue to play a role in the NRO, what you wanted was a structure that had a critical mass that allowed personnel growth and allowed a select number of people to make a career in quote ‘Navy space.’”¹⁷

Central to realizing that context was the formation of the NCST. It was decades in the making and presaged by a series of organizational changes beginning in 1971 when NRL's Director of Research, Dr. Alan Berman, moved Pete Wilhelm, and the two-dozen or so engineers then in his Satellite Techniques Branch, into the Space Systems Division of the Space Science and Technology Directorate. That placed the lab's locus of space engineering under the direct supervision of Howard Lorenzen, the hard-charging countermeasures legend who had ushered NRL into the space-based

intelligence trajectory.¹⁸ Two years later, the 15-year-old Satellite Techniques Branch morphed into the Spacecraft Technology Center (Code 7040), NRL's all-purpose hub for satellite technology with Wilhelm at its head and reporting to Herb Rabin, who became Associate Director of Research for the Space Science and Technology Division. Also created in the 1973 shifts was the vaguely named Advanced Projects Office (Code 7030) with Reid Mayo at the helm, the vaguely named Systems Development Section headed by Fred Hellrich, and the vaguely named Advanced Concepts Section (Code 7033) with Lee Hammerstrom as top manager.

There were additional administrative and organizational changes in 1978, 1980, and 1984, all of which brought more and more responsibility under Wilhelm.¹⁹ All these shifts expanded the scope of the lab's space technology portfolio and increased the number of people working on it. "What the lab was trying to drive toward was basically to get all of the space work into one organization," said Wilhelm.²⁰ And there were even bigger changes afoot.

Upper echelon planning by Defense and Navy Department officials, including the Secretary of Defense and the Secretary of the Navy, were calling in early 1984 for a "Naval Space Technology Center," whose mission, according to one document from the Chief of Naval Research (CNR), would be "maintaining a space technology base and assisting in the acquisition of space systems used by the Navy." This was part of

INFORMATION		NAVAL RESEARCH LABORATORY CODE DIRECTORY, OCTOBER 1986 WASHINGTON, D.C. 20375-5000				EMERGENCY	
Code	Name & Location	Code	Name & Location	Code	Name & Location	Code	Name & Location
COMMANDING OFFICER/EXECUTIVE DIRECTORS							
EXECUTIVE DIRECTORATE							
TECHNICAL SERVICES DIRECTORATE							
ADMINISTRATIVE SERVICES DIVISION							
GENERAL SCIENCE AND TECHNOLOGY DIRECTORATE							
SPACE SYSTEMS DEPARTMENT							
SPACECRAFT TECHNOLOGY CENTER							
SPACE SYSTEMS DEVELOPMENT DEPARTMENT							
SPACECRAFT ENGINEERING DEPARTMENT							
SPACE SYSTEMS TECHNOLOGY DEPARTMENT							
SERVICES AND OUTSIDE ACTIVITIES							
MATERIAL SCIENCE AND COMPONENT TECHNOLOGY DIRECTORATE							
WARFARE SYSTEMS AND SENSORS RESEARCH DIRECTORATE							
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REPORT CHANGES TO CODE 2020

NRL in 1986. For a short period in 1986, the Naval Space Technology Center, NSTC, transiently designated what would become the Naval Center for Space Technology, NCST. (NRL photo *NRL Code Directories 1933-2010-319.pdf*)

an overall Navy Space Policy document that was signed by the Secretary of Defense on February 6, 1984.²¹

Remarkable to Wilhelm and his leadership team was that the policy did not specify that the Naval Space Technology Center (NSTC) would be located at NRL, but that it would be established at “one of the Naval Laboratories or Centers.”²² NRL surely was the lead candidate—at least the lab denizens thought so—but there was no guarantee it would become the Center’s home. The new Navy Space Policy stressed the importance of future space systems for tactical naval operations. A set of guidelines for the establishment and operation of the NSTC²³ specified that it would:

- Provide expert advice to upper echelon Naval leaders’ offices, including the Naval Space Command, Chief of Naval Research, and the directors of classified, Navy-based space programs and projects.
- Conduct basic and applied research related to uses of space systems in support of naval missions.
- Support Navy acquisition or monitoring of space systems.
- Maintain current knowledge of space systems technology and programs conducted by other services or agencies.

Additionally, the guidelines specified the Center would include 100 or more personnel with collective skill sets in active and passive space sensors, satellite communications, spacecraft design, navigation, ocean surveillance, associated ground-based facilities and data processing, and tactical use of space assets for on-ground war operations.²⁴

In line with the way NRL funded its research and development, the guidelines stated that the Center would be “industrially funded to support space systems acquisition and operation or to conduct research in response to tasking by the Naval Material Command and/or other defense agencies.” A portion of funding for basic and applied research, in the several millions of dollars range, would come directly from the Navy in federal research funding categories known as 6.1 and 6.2. According to the guidelines, “The purpose of the direct funding is to allow the NSTC director to pursue innovative and creative research related to uses of space in naval missions and to provide short term responses to technical or programmatic issues.”²⁵

Then came the bases by which the Chief of Naval Research would make the site selection for NSTC:

- Scope of space-related activities and facilities;
- Quality and extent of personnel, facilities, and programs which the host proposes to assign to the NSTC;
- NSTC/host understanding of and commitment to uses of space in support of naval missions; and
- Other criteria recommended by NSTC OG [Oversight Group] members.

A series of intense, high-level meetings followed over the course of a year to deliberate on just where the new Center should reside. Although NRL clearly was the best candidate for hosting NSTC in that it essentially had been playing the specified roles for years, politics has a knack for bringing forth results that don't necessarily make sense. Wilhelm speculated that there may have been other organizations vying for the assignment, but said he was never able to confirm that. Remarkedly, Wilhelm, "I never thought there were any serious contenders."²⁶ Behind the scenes, Dr. Timothy Coffey, a plasma physicist who became the lab's civilian Director of Research in 1982, worked with Wilhelm to secure support for NRL from the Secretary of the Navy, Dr. John Lehman. It was no surprise that NRL was, in fact, chosen as the designee, an action made official in a letter dated March 8, 1985, from the Office of Naval Research to Captain James P. O'Donovan, the Commanding Officer of NRL at the time.

"The consensus of these deliberations was that the Naval Research Laboratory (NRL) is the most appropriate host for the NSTC," the letter stated, adding that NRL already was officially known for its "Navy-wide leadership in the development of space systems for the Navy and has amassed a fine record of accomplishment in this regard."²⁷

In preparation to take on this higher-profile role in the future of Navy space activities and operations, NRL leadership folded the lab's Aerospace Systems Division into the Space Systems Division as a way to retain coveted and limited Senior Executive Service leadership slots. It took another year (until October 1, 1986) to complete the process of establishing the new space technology center. That is when the Space Systems and Technology Division was renamed the Naval Center for Space Technology and was assigned the administrative code 8000.²⁸ Wilhelm, who assumed the directorship of NCST, points out the name is a permutation of the name in the Navy Space Policy documentation—the Naval Space Technology Center—because any Navy entity that ends with the word Center traditionally had a higher-echelon status in the Navy than would be appropriate for NRL's role in space technology. So NSTC became NCST.²⁹



NCST logo.

On October 1, 1986, the Naval Center for Space Technology officially started operating under this new name. Second to NCST director Pete Wilhelm was Associate Director Fred Hellrich, who had become adept, during years of work in NRL's space technology programs including Poppy, at key managerial functions and at communi-

cating up and down the authority chain. NCST's initial organizational structure featured three Departments, 8100, 8200, and 8300. These codes designated, respectively, the Space Systems Development Department (SSDD) under Superintendent Robert Eisenhower; the Spacecraft Engineering Department (SED) under Superintendent Robert (Bob) Beal; and the Space Systems Technology Department (SSTD) under Superintendent Lee Hammarstrom.

The establishment of NCST consolidated and reinforced NRL's role as the Navy's primary space technology laboratory. For his part, Betterton wanted to build on this momentum by taking steps to preserve for NRL as much influence as possible in space technology development for intelligence gathering purposes, even though the lab no longer was building operational satellites (as opposed to prototypes). Toward that end, he envisioned that Wilhelm, the director of NCST, would also be designated as the Chief Systems Engineer for what essentially was the follow-on classified work that NRL would do for the NRO as well as other Navy-related space programs.

"This would have given the director of NCST a seat at the table with the director of the NRO," said Betterton. "It would have given him another seat within SPAWAR," a command-level component of the Navy, which had responsibility for the unclassified space acquisition programs like the Fleet Satellite Communications System (FLT-SATCOM).³⁰ And, Betterton continued, "it seemed like a good way to tie everything together ... and try to create some sort of critical involvement of resources, people and money for whatever the Navy's interest [in space] was going to be." This vision never came to be, however. "We made some baby steps and then it fell apart," Betterton said, pointing to an inability of obtaining a sign-off from top leaders in the several Navy commands and the Office of the Chief of Naval Operations (OPNAV), which would have been required to weigh in with positive votes.³¹

The reality on the ground was that NRL's space technology organization would be more on its own than it had been since it began building up from its roots when Ernst Krause secured the lab's upper atmosphere researchers access to captured V-2 rockets. True, the space technology team gained status with the establishment of NCST at NRL, but that came with a cost. Until then, much of the money that ran the space technology program at NRL came from NRO. But now, NRL's role in NRO work would focus on initial technology and prototype development, and acquisition and technical oversight, but the actual satellite-building phase would be transitioned to industry. NCST would have to find new sources of funding to keep it going.

A 2005 analysis by the National Academy of Sciences of what space capabilities the Navy likely would need in the future assessed NRL's past status in the arena of space technology development this way:

"Through the early 1980s, NRL's largest effort was in support of the development of classified prototype surveillance satellites. These developments indeed were successful, to the degree that the sponsoring agency (NRO) decided to go into serial production of such satellites. Since NRL was a research laboratory and not a manu-

facturing facility, the production of the next generation of satellites was transferred to an industrial organization. This transfer left many members of the NRL staff without sponsor support and necessitated a rather traumatic drawdown in the number of NRL personnel available to manage the development, acquisition, and launch of full satellite systems.³²

So, just as the Navy was raising NRL's status for space technology, the laboratory's traditional role in meeting the Navy's needs in space was undergoing radical change.

¹ Thomas Betterton, interview with author, July 18, 2012.

² Applied Research Laboratory, The Pennsylvania State University (ed.), *From the Sea to the Stars: A Chronicle of the U.S. Navy's Space and Space-related Activities, 1944–2009* (revised and updated edition, 2010), <https://www.history.navy.mil/> p. 201; Art Collier, interview with author, April 22, 2012, and January 29, 2013.

³ Betterton, interview with author, July 18, 2012.

⁴ Betterton, interview with author, July 18, 2012; Art Collier, personal correspondence.

⁵ Betterton, interview with author, July 18, 2012.

⁶ Betterton, interview with author, July 18, 2012.

⁷ Chris Dwyer, interview with author, February 9, 2012.

⁸ Betterton, interview with author, July 18, 2012.

⁹ Betterton, interview with author, July 18, 2012; Robert Eisenhower, interview with author, April 9, 2013.

¹⁰ Dwyer, interview with author, February 9, 2012.

¹¹ Betterton, interview with author, July 18, 2012.

¹² James Winkler, unpublished memoir shared with author, 2012, p. 44.

¹³ Winkler, 2012, pp. 48–49.

¹⁴ <http://heasarc.gsfc.nasa.gov/docs/heasarc/missions/solrad11.html>.

¹⁵ Art Collier, personal correspondence, 2013.

¹⁶ Art Collier, personal correspondence, 2013.

¹⁷ Betterton, interview with author, July 18, 2012.

¹⁸ Peter Wilhelm, interview with David van Keuren, November 19, 1987.

¹⁹ <http://ncst-www.nrl.navy.mil/NCSTOrigin/NCSTOrigin.html>.

²⁰ Wilhelm, interview with David van Keuren, November 19, 1987.

²¹ *From the Sea to the Stars*, pp. 114–116.

²² Memorandum for the Chief of Naval Research, Deputy Chief of Naval Material (Technology), signed by Melvyn R. Paisley, February 29, 1984.

²³ Naval Space Technology Center: Guidelines for Establishment and Operation, 13 February 1984, provided to author by Peter Wilhelm and now in Naval Research Laboratory's History Office. The document was attached to a Memorandum for the Chief of Naval Research and the Deputy Chief of Naval Material (Technology) and signed by Melvyn R. Paisley, who was at the time the Assistant Secretary of the Navy (Research, Engineering and Systems). The memorandum is dated 29 February 1984 and has the designator 7906-18:JNH:mvf.

²⁴ Naval Space Technology Center: Guidelines for Establishment and Operation.

²⁵ Naval Space Technology Center: Guidelines for Establishment and Operation.

²⁶ Peter Wilhelm, email to author, September 4, 2013; Peter Wilhelm, interview with David van Keuren, November 19, 1987.

²⁷ Memorandum from Chief of Naval Research to Commanding Officer of the Naval Research Laboratory, dated March 8, 1985.

²⁸ *From the Sea to the Stars*, p. 110.

²⁹ Peter Wilhelm, interview with author, February 16, 2012; Peter Wilhelm, interview with David van Keuren, November 19, 1987.

³⁰ Art Collier, personal correspondence, 2013.

³¹ Betterton, interview with author, July 18, 2012.

³² National Research Council, *Navy's Needs in Space for Providing Future Capabilities*, (Washington, DC: The National Academies Press, 2005), p. 157.

THE CHANGING NEIGHBORHOOD

It was during these major transitional years in the mid-1980s for NRL's space technology program when John Schaub, a freshly minted double major in mechanical engineering and physics from the Georgia Institute of Technology, joined the Mechanical Systems Branch (7734) of the Space Systems Division (7700), which was in the hands of Bob Beal. This was in early 1985, a year prior to the formation of the Naval Center for Space Technology (NCST). Schaub's experience symbolized the new direction that satellite building would take at NRL.

"I airdropped into a beehive of activity," recalls Schaub, who by 1998 was Associate Superintendent of the Spacecraft Engineering Department (SED), then one of three major divisions in the NCST. In particular, Schaub was assigned to work on a separation system that would eject a cluster of satellites from the cargo bay of a NASA Space Shuttle.¹ The satellites were installed on what then was called the Shuttle Launch Dispenser, or SLD, a variation of NRL's Multiple Satellite Dispenser (MSD), which Pete Wilhelm and his fellow engineers designed so that it would integrate with the Atlas F booster system. The MSD first flew in April 1976 as the country was revving up for its Bicentennial celebration.

Schaub could not have known it when he started, but one year later he would be negotiating two major transitions at NRL that would become emblematic of the lab's future in space technology. On January 28, 1986, Schaub, the nation, and the world were stunned when Space Shuttle Challenger exploded on a cold winter morning 73 seconds after liftoff. An investigation panel, including famed physicist Dr. Richard Feynman of the California Institute of Technology, later determined that unusually cold temperatures at the Florida launch site had rendered brittle a large rubber O-ring, essentially a gasket, in one of the shuttle's solid rocket boosters, allowing hot gas to escape and ignite the liquid fuel of the main engine.

For the NRL team, the disaster had direct and dramatic consequences. The shuttle fleet suddenly went entirely offline for an indefinite period of time. Yet the national requirement for the space systems that the shuttle was supposed to help install in orbit continued unabated and with no less of a sense of urgency. The only other practical means of access to orbit were Titan rockets manufactured by the Martin Marietta Company. NRL had contracted with a precursor of the firm, the Glen L. Martin Company, in the 1950s to build the Viking rockets that kept NRL in the space business after the V-2 supply ran out and the boosters for the Vanguard project.²

The sudden shift of boosters required Wilhelm's engineers at NCST to redesign the Shuttle Launch Dispenser for its new perch atop a Titan rocket. The SLD became the TLD, the Titan Launch Dispenser.³ It was an engineering and design challenge, but it was one that unfolded within a cultural shift as well, the one centered on NRL handing its previous satellite-building and production role off to contractors. "We had the transition contractor here at NRL for the first build/launch," Schaub said, referring without specifics to an aerospace company. "The goal was for them to transition the resulting engineering into their production environment and to produce more of these units back at their plant."⁴

To increase the chances of success, the company had a role in the TLD project from day one. The industry partner "would provide a transition team, which would participate in the initial design and development phase, production phase, integration, test and launch, and post-launch phases," recalled satellite engineer James Winkler, then head of the Program Development Office in NCST's Space Systems Development Department.⁵

NCST had pulled off such an effective transition, Schaub said, that "you almost put yourself out of a job. The follow-on programs were being done completely by contractors," Schaub noted, adding that NCST has kept an important hand in the game by "advising our government customer in helping them troubleshoot and solve problems."⁶ To Captain Art Collier, who succeeded Betterton in 1986 as Special Projects Office Director (by which time the office had been designated as SPAWAR 004-5 within the Space and Naval Warfare Systems Command), "the partnership with industry in this manner is a wonderful example of how to most effectively use a government laboratory to transition high risk programs."⁷

For his part on the SLD project before the Challenger disaster, Schaub was set in front of a drafting board with mechanical pencils, the design tools that preceded computer-aided design (CAD) programs. He was given the task of designing a dozen spring-operated separation cartridges that would enable the multiple-satellite-bearing SLD to deploy from a canister in the shuttle's cargo bay and begin the process of shuttling and depositing the satellites to the specific orbits that Wilhelm's orbital experts had calculated to be the best ones.⁸ This would be followed by lots and lots, and lots and lots, of testing.

"One properly designed test is better than a slew of analyses," Schaub stressed, referring to calculation-based analyses. "We have a reputation for wanting to build more engineering models and prototypes as early as possible in the program for testing." On paper, this approach appears to cost more. "But I guarantee you," Schaub said, "that if you take this approach, when you have your whole team up and running, then you are not going to lose as much schedule time to unanticipated issues. That culture has been ingrained in me from the very first day here ... Build the hardware. Test the hardware. Do the analyses too, because you have to, but trust the hardware. Because you don't get a second chance."



Future Director. Shown in his office in late 2004, John Schaub became superintendent of NCST's Spacecraft Engineering Department (8200) in 2006, and had served as acting superintendent prior to that. In 2016, he succeeded Peter Wilhelm to become the second director of the Naval Center for Space Technology. (NRL photo DG7P4069.jpg)

Designing and building the Titan Launch Dispenser was an enormous job, literally. “The TLD spacecraft was the largest structure the NCST had ever built,” Winkler said, adding that it was designed to fit in the 14-foot-diameter volume of the Titan IV fairing. Winkler was in charge of the complex electrical harness, with a dozen Medusa heads of wiring, which orchestrated connections throughout the spacecraft.⁹

Even before Schaub saw the first launch carrying the TLD bearing the satellite-separation mechanism he helped design, he witnessed the launch of another satellite. As much as anything else, this launch symbolized NCST's shift away from its former heavy dependence on NRO to work with other sponsors. In this case, a new deep-pocketed sponsor that helped fill the gap was the Strategic Defense Initiative Organization, SDIO, whose mission then had become known in popular parlance as “Star Wars.” This was the vision developed by President Ronald Reagan and partners at Lawrence Livermore National Laboratory and elsewhere. Reagan's stated aim was to remove the specter of nuclear annihilation by assembling a multi-tiered, ultra-high-tech set of detectors, trackers, and interceptors that would amount to a national-scale shield against a nuclear attack. The Soviet Union might still have had thousands of nuclear weapons directed at New York, Washington, Chicago, San Francisco, and many other U.S. targets, but the Strategic Defense Initiative (SDI), Reagan dreamed, would one day take their actual threat away.

The Laser Atmospheric Compensation Experiment, or LACE, was an early experimental component of the SDI.¹⁰ It was not supposed to be a large-scale project for NRL's satellite technology team, but the Challenger explosion changed that. The original plan for LACE, devised soon after the White House announced the SDI in March 1983, was to modify a NASA satellite that already had been in orbit. Originally, a space shuttle was to retrieve the spacecraft and bring it back down to the surface where it could be modified into an SDI platform for learning how best to shoot laser

beams through the turbulent atmosphere without dissipating their power. That was just one requirement if lasers would one day be able to take out incoming, nuke-laden ballistic missiles. The plan called for the Shuttle to retrieve a low-profile, bus-sized, 12-sided orbiting framework—the Long Duration Exposure Facility (LDEF). Like paintings in a gallery, swatches of different kinds of materials had been attached to the LDEF's panels where for years they had been passively undergoing endurance and performance tests in space's low-pressure, low-gravity, high-radiation environment.¹¹

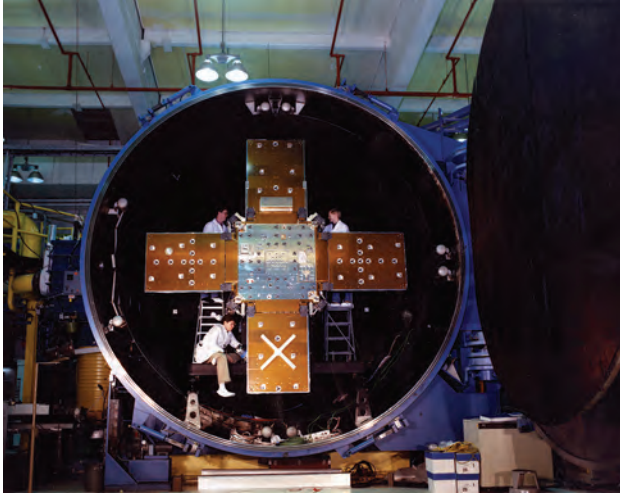
“The plan was to bring the LDEF back, and then we were going to modify it by putting two very long booms on it, sticking out, and then a target board on the bottom,” Schaub explained. “And then scientists from MIT Lincoln Laboratories [a federally funded laboratory with a focus on national security and a technical base that includes optical sciences and technologies] were going to do atmospheric compensation experiments with lasers to try to see if you could actually compensate for the distortion of the beam as it goes through the atmosphere.”¹²

To Bob Beal, who was head of all the mechanical work under Wilhelm, the task was a distraction that would take away available resources from his primary concern, which then was still the Shuttle Launch Dispenser.¹³ But Beal's boss, that is, Wilhelm, knew it was in the organization's best interest to nurture new sponsors like the SDIO. Dr. Donald Horan, who would assume managerial roles on a number of high-profile missions at NCST, took on the role as the Chief Scientist and Director of Operations on the project.¹⁴

From a cultural point of view, a new task with a new sponsor was a challenge for the space technology staff. “We were being asked to work for two customers at one time and the organization was not set up to do that,” Schaub said, though NRL's space technologists had been in a similar position during the Poppy days when they were working on both an ELINT program and the GPS system.

And then Challenger blew up. And that meant LDEF was not coming back any time soon to Earth where engineers at NRL and elsewhere had plans to modify it for the Laser Atmospheric Compensation Experiment. Despite the shutdown of the shuttle program for an indefinite period of time, SDIO still wanted to move forward with atmospheric compensation experiments. To do that now, though, would require an entirely new satellite. “I suddenly went from being a mechanical engineer working on an experiment to being a lead mechanical subsystems manager on the LACE spacecraft,” Schaub said. A new sense of urgency infiltrated the space technology group and a lot more money from the new sponsor came with it. By its end in 1993, the program would take nine years and cost nearly \$130 million.¹⁵

For those in the trenches and now dealing with two major projects at once, these seemingly enormous managerial, structural, and administrative changes would not be at the center of their attention. Said Schaub: “We had jobs to do. We had missions to accomplish.”¹⁶



Big Blue. The NCST-built spacecraft for the SDI-sponsored Laser Atmospheric Compensation Experiment undergoes tests in the enormous vacuum and temperature chamber known as Big Blue. (NRL photo 82441(R-29)3.tif)

For the rest of the decade and, for some, into the early 1990s, Horan, Schaub, and a few dozen NCST colleagues worked day and often night shifts on hundreds of technical and engineering details for the LACE spacecraft. “By 1987, the simple, spaceborne target had evolved into three separate sensor arrays with a total of 210 sensors capable of characterizing ground-based laser beams with continuous-wave or pulsed emission in the visible, UV, and IR bands,” Horan explained. “Also, SDIO began discussing the addition to LACE of an instrument to take video images of rocket plumes by their UV emission.”¹⁷ And that became the add-on experiment known as Ultraviolet Plume Instrument (UVPI).

The fundamental principle of the primary experiment, the atmosphere compensation tests, involved first measuring and characterizing the distortions the atmosphere would impose at any given moment upon a spaceward laser beam, and then compensate for, or nullify, the distortions. The technology for achieving that end is known as “adaptive optics,” in which precisely controlled mirrors and lenses in the ground system deliberately pre-distort the upgoing laser beam such that the specific distorting effects of the atmosphere would essentially refocus the beam rather than distort it. This is, in a way, a case where two wrongs make a right.

LACE launched on Valentine’s Day in 1990. “Everybody thought that it was appropriate that a satellite called LACE was launched on St. Valentine’s Day,” observed Horan.¹⁸ Schaub was at the launch at Cape Canaveral, Florida; his wife was not with him, he pointed out. In fact, he noted, uncertainties in the launch schedule actually led to changes in the couple’s wedding planning. “You throw yourself into these projects and put everything else second,” Schaub observed, affirming a prioritization that characterized his space technology predecessors at NRL since the V-2 days in the

late 1940s. Remarked Schaub, “You have to have the right partner for that to happen, and if you don’t take care of business at home, you can lose what you have there.” He knew this had happened before to oversubscribed colleagues at NRL and other venues in the satellite-making culture. Schaub made it part of his own managerial mindset to keep this tension in mind both for himself and for those who would work for him.¹⁹

In the initial days and weeks after the LACE launch, he and colleagues spent many hours at the Blossom Point ground station in southern Maryland checking the spacecraft’s systems, which included, among other superlatives, the longest retractable booms that had ever flown in space. When outstretched in opposite directions—one in the direction of motion and one in the trailing direction—the two booms spanned a football field. On the end of the forward-facing boom was an arrangement of 252 cornercube retroreflectors. These were optical elements designed and placed such that they would send any laser beam essentially straight back in the direction from whence it came.

There also were other sensor arrays on the spacecraft, designed and built for NRL by Instrumentation Technology Engineering, Inc., a small company in nearby Silver Spring, Maryland. The 85-element, silicon-based Visible Sensor Array on the Earth-facing side of the spacecraft was designed to measure laser emissions from the Short Wavelength Adaptive Techniques (SWAT) program’s argon ion laser located in Maui, Hawaii. The 85-element Pulsed Sensor Array (each sensor was housed with a Visible Sensor element) was suitable for testing high-power, pulsed excimer and free electron lasers. Finally, with a 40-element Infrared Sensor Array, LACE operators could measure laser blasts from the Low Power Chemical Laser (LPCL) located at White Sands, New Mexico.²⁰

Before these were going anywhere near orbit, they had to be tested and retested for space worthiness in a thermal vacuum chamber, noted Christopher Dwyer, an electrical engineer who has been at the lab since 1985. This task fell onto his shoulders even though he had no expertise in the area. It was part of the NRL culture for managers to task their engineers with jobs and then to have confidence that the job would get done. “So I educated myself a little bit on optical components, like lasers and optical benches, to give myself at least a vague idea of how we might do that,” Dwyer recalled. “I pretty much decided at that point that I was in over my head, so I picked up the NRL phone book and looked for who in the Optical Sciences Division might be able to help me with this.” The expertise for designing and carrying out the tests for the optical elements in fact was right there on campus, which is so often the case at NRL and is one of the lab’s most valuable traits to its scientists and engineers and, Dwyer would say, to the country. As a result of that blind call, he noted, he and his new coworkers in the lab’s optics division got the job done. “That job was an example of what makes this place, the lab, such an interesting and neat place to work,” Dwyer noted. The backstory of each satellite project is rife with these sorts of collab-

orations without which the spacecraft would never make it to the launch pad the way LACE did, Dwyer pointed out.

Another one of those collaborations for LACE centered on the clocks that kept track of everything—when signals were arriving or leaving this or that component of the system, exactly when optical elements needed to be adjusted and then adjusted again, etc. “You needed to synchronize everything so that everything happens at the right time,” Dwyer said. “So in this satellite was a [master] clock that would put out a signal, and from that signal, timing across the satellite would be set. But you needed to get that [master] timing signal to the various boxes on the satellite that needed it. And pretty much every box needs the signal. So I built the box that interfaced with this clock and it distributed the timing signal to the other parts of the spacecraft that needed it.”²¹

The booms were yet another challenge. The huge gangly booms required finesse on the part of those who operated the spacecraft. Move the leading boom out, for example, and the length of trailing boom also would have to be adjusted to maintain the spacecraft’s overall moment of inertia. Failure to do that would set the spacecraft into a rocking motion. It was related to the problems that earlier NRL engineers, including Wilhelm, encountered with boom-based gravitational gradient stabilization systems. And even before the booms were integrated into the spacecraft as it was being built in the high bay of Building A59, they underwent extensive testing. “Just testing that boom on the ground was interesting,” Schaub recalled, “because it could not support its weight in one G,” that is, under normal surface gravity. The solution for the testing phase, by the Able Engineering Company, an aerospace contracting firm in Goleta, California, that specialized in deployable structures, was to float the booms in a 150-foot-long pool of water with the help of the equivalent of foam floaties that parents strap onto their babies on summertime pool days. Said Schaub: “We paid these poor workers to work 24 hours a day for weeks doing lifecycle testing and I remember putting up a case of Budweiser as a reward for when they were finished.”²²

Once LACE was in orbit, the several-week phase of engineering, evaluation, and calibration (EE&C) at Blossom Point was a crucial process too. “We don’t give the satellite over to the experimenters until we have a chance to make sure we are comfortable with everything,” Schaub explained. Once the SDIO-sponsored spacecraft, including all its subsystems, such as booms, sensors, and communications systems, checked out, a large collaboration involving scientists and engineers at NCST, Lincoln Laboratories, the Air Force, and other government and academic institutions around the country was able to do experiments using LACE.

As the satellite passed over the laser site at the Air Force Maui Optical Station (AMOS) on the Pacific island of Maui, for example, operators there shot laser beams up and measured the properties of the reflected beam to develop a model of moment-to-moment atmospheric distortion. Using that model, the system then instantly sent commands to control deformable mirror and optical elements, which then pre-

shaped upwardly going laser pulses to compensate for the just-measured atmospheric distortions. The various sensors on the spacecraft made measurements of the laser blasts to help the researchers determine how well the beams were focused and how much optical power ended up reaching the spacecraft. In an operational system in space, “fighting mirrors” would reflect lethal laser energy—protected from dissipation due to atmospheric distortion using the LACE-developed atmospheric compensation techniques—at ballistic missiles targeted at the United States or allied nations.²³

For the younger contingent of NCST engineers who were put on the task, the LACE project became a bonding exercise. “We were this young energetic inexperienced team and we were off on our own,” Schaub recalled fondly in an interview. “We had great success and we are proud of that.”²⁴ The LACE project, the first major NCST project that was funded by the SDIO, came to a close in 1993. The spacecraft remained stable enough after that, Horan noted, so that its retroreflectors could passively support ground-based laser communications and tracking tests. The spacecraft reentered Earth’s atmosphere in May 2000.²⁵



LACE Team. The management team for LACE included, from left to right, Dan Penn, Bill Adkins, Bob Palma (LACE program manager), Paul Regeon, John Schaub, and Dr. Don Horan. At LACE leadership meetings, managers began wearing white Stetson hats, a symbol of the cinema hero in Westerns, to signify the managers’ responsibilities to protect their team members from “evil” external forces over which they had little or no control.

Even before LACE became front and center in NRL’s space technology portfolio at the behest of the Strategic Defense Initiative Organization, lasers became the heart of a more grassroots effort within NCST to develop laser-based technologies as alternative means of communications and satellite ranging.

Radio frequency (RF) signals have been elemental to NRL since the lab opened its doors in 1923 with almost nothing but radio engineers on the original technical staff. And RF has been part and parcel of every space-bound payload the lab has launched since Vanguard 1 became humanity’s fourth-ever satellite, on St. Patrick’s Day in 1958. RF was the basis of NRL’s Minitrack system associated with the Van-

guard program, the basis of the multi-satellite-tracking NAVSPASUR system Mini-track evolved into, and the basis of much of the tracking of orbiting objects since the advent of the Space Age.

But RF has not been the only game in town for this purpose, at least not since 1964 when a team of engineers at NASA's Goddard Space Flight Center in Greenbelt, Maryland, demonstrated it was possible to use the then recently invented laser technology as an alternative to RF techniques for determining the range to orbiting satellites. The basic principle of laser ranging is to accurately measure the time it takes for laser pulses to make a round trip from a ground-based laser to a satellite passing overhead and then back down to a sensitive laser light detector near the emitter. "Compared to the 50 or more meter accuracy of the microwave radars of the period, the 2 to 3 meters accuracy of the early experiments of this period represented a quantum leap in capability for precise orbit determination," according to a chronicle of NASA's first 30 years in the business of satellite laser ranging (SLR).²⁶

Nearly a half-century later, NRL and the Naval Center for Space Technology built a laser ranging capability of its own—known as the Optical Test Facility (OTF)—at the lab's 158-acre Midway Research Center (MRC) in Stafford, Virginia,²⁷ near the Marine Corps Base at Quantico. The MRC's primary role is to develop scientific techniques for evaluating the performance of satellite missions. For its part in this broad endeavor, the OTF relies on optical techniques for improving the tools and techniques that different satellite programs rely on for monitoring the ephemerides (orbital trajectories) of their respective spacecraft. At the OTF are a neodymium-YAG laser and a one-meter telescope customized by NCST specialists. The telescope has a unique combination of slewing speed and pointing accuracy, noted Dr. Linda Thomas, senior research engineer in the Electro-Optics Technology Section (Code 8123) of NCST's Advanced Systems Technology Branch (8120). Said Thomas: "The telescope can slew 25 degrees per second. Watching the telescope move is one of the most beautiful things. It is an engineering marvel."²⁸

That facility emerged from years of climbing up a learning curve of using laser light for both laser ranging and laser communication. "The project we were working on at first was fairly low-powered laser communications for space-to-space communications" between spacecraft, recalled electrical engineer Anne Reed, who joined the fledgling effort in 1985 as a co-op student. Besides Reed and one other co-op student, the tiny section at the time included only the section head and one engineer.²⁹

"We were doing fundamental research investigating how to control laser diodes and deal with bit error rates," explained Reed, who rose to section head in 2002 and left the lab in 2008, at which time she handed the reins to colleague and electrical engineer Dr. Bill Scharpf. "Some of the work we did was in-house, some was with space contractors, looking at systems they were developing, and some was doing testing for systems that were being jointly government/contractor developed."³⁰

Laser communications would always remain important in the section's research portfolio, but an outside sponsor asked the group to look into satellite laser ranging, with an eye on achieving more accurate position measurements of satellites that were of interest to that organization. One of the first steps was to visit several NASA laser-ranging research sites, Reed recalled. With lessons learned from those visits, the section, led by Dr. Charmaine Gilbreath at the time, procured a laser system and built a timing system—in what then was Building 58 at the front of NRL's campus and now is a grass field—for comparing the emission and reception times of laser pulses. For the first experiments with the equipment, they took the system down to the Malabar Air Force site in Palm Bay, Florida.

“We went down and did several laser ranging campaigns against satellites of interest to our sponsor,” Reed said. The team also did experiments as part of a project called Red Tigress for another sponsor. “We were doing ranging off of rocket plumes” with the objective of developing new ways to identify and track enemy missiles. Each campaign, all of them in the late 1980s and early 1990s during the early years of the Strategic Defense Initiative, involved a close-knit group working all night and much of the day for multiple weeks.

After these campaigns were completed, Reed recalled, “we brought our equipment back here to NRL. In classic NRL style, we were not only the engineers but also the ‘moving company’ so we drove the equipment back ourselves.” In the truck, Reed recalled, was a laser the size of a dining room table, racks of timing equipment and other electronic components, atomic clocks, and sundry other research necessities. And, because these campaigns were done in Florida, there also were boogie boards and other beach accouterments to bring back home.

The sponsor supported a second set of tests in collaboration with the Air Force Research Laboratory at Kirtland Air Force Base in New Mexico, the location of the Starfire Optical Range, which included a 3.5-meter telescope. The tests were of the same sort as the ones in Florida. But with the larger telescope in the circuit, lower levels of light returning from laser-tagged spacecraft would be detectable. And the NRL team's laser-timing system would be able to connect the dots between the emission of laser pulses and the detection of reflected photons.

The optics team also wanted to become productive members of the larger laser-ranging research community, including the collaborative International Laser Ranging Service (ILRS), so they set their sights on developing a laser ranging system whose data would pass muster with NASA and the other ILRS members. Among other advantages, being part of this larger community would give the NRL team access to more orbiting “targets” to work with, as well as a huge global cache of laser ranging data that would help in the cause of determining orbital trajectories with ever more precision.

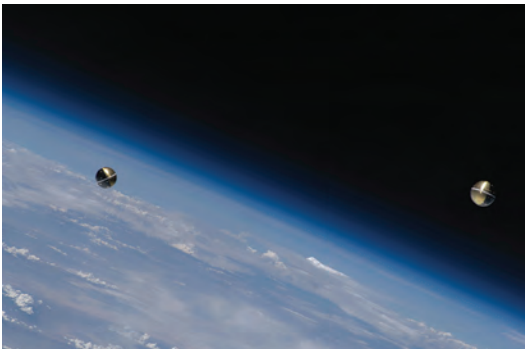
To realize these ambitions, the team needed its own optical facility and Gilbreath managed to convince laboratory leadership that buying a one-meter telescope for

harvesting reflected photons would be a good use of the lab's capital funds devoted to building up facilities and basic capabilities. Together with the laser and timing systems the team already had built, the section now was on its way to having an entire laser ranging system, replete with a photon-catching telescope like the other ILRS players. Soon after scoring this administrative win, Gilbreath took on new responsibilities outside of NCST. As Reed took the baton for the section, she recruited the support of several other sponsors to accumulate enough money to get the entire facility built. The telescope was based in part on the design of a NASA instrument and it featured customizations orchestrated mostly by the late Mark Davis, the go-to man for all things that no one else knew how to do.

"The different characteristic that was most important to us was the ability to move around very quickly so that we could range to multiple satellites in a short period of time," Reed explained. "Take some shots. Take some shots. Take some shots. I want to look at this one. I want to look at that one. I want to come back to this one. That was not an important requirement to anyone else at the same level as it was important to us. Mark spent a lot of time early in the new millennium working with the supplier and getting something delivered that would meet our needs." After several years of development and fabrication, the telescope was finally delivered to the MRC site in the summer of 2002.

Among the various projects the optical team contributed to in the first decade of the 21st century was the Atmospheric Neutral Density Experiment (ANDE), a brain-child of NRL colleague Andrew Nicholas of the lab's Space Science Division. For their part, the optical team used their laser-tracking facility at MRC to help track ANDE's pair of laser-retroreflector-bearing microsattellites. The two microsattellites, which were the same size but of different masses, slowly separated after being deployed together, thereby providing researchers with a framework for measuring subtle spatial and temporal variations in drag due to geomagnetic interactions in low Earth orbit. The first ANDE mission was in 2006 and ANDE-2 was three years later.³¹

In another mission in 2009, the Charged Aerosol Release Experiment (CARE), the team contributed, with many collaborators including Dr. Paul Bernhardt of NRL's



Space Twins. Consisting of twin spheres named Castor and Pollux, the ANDE-2 mission is shown here shortly after deployment from Space Shuttle Endeavour on July 30, 2009. (Credit: NASA)

Plasma Physics Division, to the study of the formation and evolution of high-altitude noctilucent clouds that normally can only be seen when illuminated underneath by the setting sun. In this mission, the optics team deployed laser tracking of aluminum oxide dust released by the rocket's fourth stage into the upper atmosphere (at an altitude of about 175 miles) where it formed artificial noctilucent clouds for subsequent measurement and tracking.³² In the following years, the team worked on another project, SpinSat, which astronauts aboard the International Space Station deployed into orbit on November 28, 2014. SpinSat's primary mission is to demonstrate new thruster technology, but it also bears retroreflector arrays optimized to help ground-based laser trackers determine the attitude of spacecraft as it moves in their orbits.³³

Amidst all this laser ranging work, laser communications remained on the team's radar screen too. The section was growing in both personnel and resources, so in 1999, the group built the smaller but mobile TRTEL, short for "transportable telescope." The first experiments with this instrument, with its commercial 16-inch Meade telescope inside, were in New Jersey at the Lakehurst Naval Station, next to Ft. Dix. "We were right on the site of where the Hindenburg crashed in 1937," Reed noted.³⁴

These were air-to-ground experiments using a rented blimp painted with a huge Tommy Hilfiger advertisement. The long-term goal here was to develop systems for over-the-horizon laser communication in which a blimp, plane, or some other airborne surveillance platform could pass back massive amounts of data to receivers anywhere in the platform's line of sight. At the same time, these experiments applied to potential applications in space. "We are a space center, so we always think about going back to try a system we are testing on the ground or air for space purposes," Reed said.

The most ambitious vision the team pursued was known as Revolutionary Imaging Technology (RIT). It brought together the disciplines of optical communications, imaging, and laser ranging. The basic idea was to eventually launch and precisely arrange in space multiple telescopes that together, by way of sophisticated data and communications linkages, would behave like one huge telescope for doing high-resolution imaging from space. Astronomers have developed similar systems for directly imaging celestial objects from the ground.

The Tommy Hilfiger blimp experiments, as well as similar blimp experiments at NASA's Ames Research Center at Moffett Field, California, provided preliminary data and lessons regarding the role of laser communications in this concept. "The first step was to put up a single small aperture [for harvesting photons], and cover it up with a mask with holes in it so that it would emulate a perfectly synchronized interferometer," Reed explained. In short, each hole of the mask modeled one satellite of a cluster and all of the holes together modeled the entire cluster. "It is a first step that allowed us to collect imagery from what an actual interferometer would be like without having to worry about the mechanics of the separate elements moving around relative to

each other,” Reed continued.³⁵ A key challenge in the system would be managing the vast amount of data involved both in the imaging and in the metrology systems.

“You would have many optical telescopes sitting up in space. The data would have to come down. The satellites would have to communicate. So you need laser ranging and laser communication between all of those to know exactly where every element is in the array with respect to each other and with respect to the ground. Additionally, the necessary active control of each of those elements will significantly increase the complexity,” Reed pointed out. With their collective eye on space, the team rented a high-altitude balloon for another round of experiments. The optics packages were flown up to 100,000 feet out of Holloman Air Force Base in Alamogordo, New Mexico—near the White Sands Missile Range where early NRL researchers launched instrument-laden V-2s to do atmospheric science. “We flew that experiment a month after 9/11, in October 2001,” Reed noted.

“The laser-based imaging piece is a spiral development,” added Thomas. “You show the capability. And each step indicates the next step. You go from blimps to a high-altitude balloon, and then potentially convince the sponsor that you would be able to fly something like this in space.”³⁶ As sometimes happens at the leading edges of R&D, this particular technology-development spiral, RIT, ended at NRL when the sponsor, as Scharpf recalled it, “decided to go another way.”

Common to several of the Advanced Systems Technology Branch’s laser-based projects are those retroreflectors, which are gorgeously machined shapes with reflective surfaces affixed to aircraft or spacecraft such as LACE. As on LACE, retroreflectors are deployed in arrays and are designed to direct photons from incoming laser pulses to receivers on the ground, in the air, or in space.

Among the higher-profile retroreflectors are those placed on the moon and on two satellites of the Global Positioning System. “A lot of the laser ranging that NASA and the international community does is for geodetic purposes to understand how the Earth is changing,” remarked Thomas. Changing sea levels and motions of tectonic plates are among the geodetic measures of interest to this community. The GPS system, with its many satellites in a perpetual cycle of replacement and upgrades, offered a versatile opportunity for geodetic laser ranging. In 1993, NRL’s Ron Beard, long-time head of the Space Applications Branch, along with Dr. Carroll Alley, a physicist at the University of Maryland who was among the principal players in getting retroreflector arrays on the moon during the Apollo era, and NASA representatives, convinced the Air Force of the value of placing retroreflectors on GPS satellites. “The satellites are broadcasting where they are and what time it is, and their job is for improving positioning,” Thomas explained. “So, in addition to RF monitoring through the GPS receiver network on the ground, if you add a component of satellite laser ranging, you improve the quality of analysis of the whole geodetic structure of the planet.”³⁷

In what amounted to a final-hour integration into GPS satellites launched in August 1993, and March 1994, respectively, Air Force managers of the system did include

retroreflector arrays, which NRL procured from the Moscow-based Institute for Precision Instrument Engineering (IPIE), Thomas noted. The Office of Naval Research sponsored the program with the primary goal of improving the ability to monitor the behavior of atomic clocks aboard the satellites.

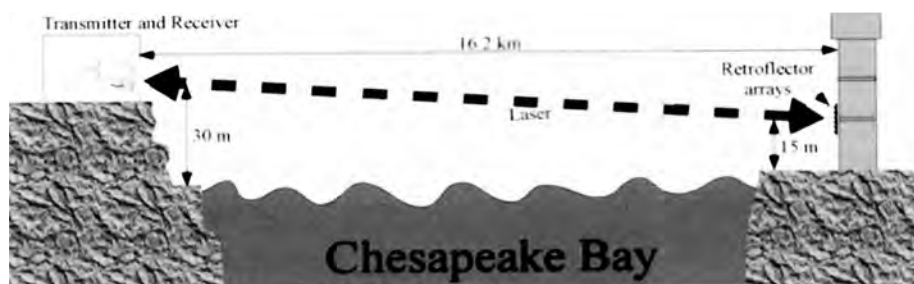
But there were other stakeholders, among them the Department of Transportation and the National Oceanic and Atmospheric Administration (NOAA), Thomas noted. They were “concerned about improving the quality of the terrestrial reference frame,” she added, since this is the basis of geodetic products ranging from ice level variation maps to monitoring of tectonic plate motion to tests of general relativity and determination of subtle gravitational variation on a planetary scale. On the wish list for NASA, for example, were such capabilities as monitoring sea level rise to millimeter differences and annual rates of change of one tenth of a millimeter (0.1 mm). In 2012, Thomas pointed out, “we got agreement that some of the GPS Block III vehicles will be able to host laser retroreflector array payloads,” with the first ones slated for launch in 2019. She noted that key to this inclusion was the ability of the NCST optics group to serve as an honest broker for communication between stakeholders. “NASA and the Air Force did not understand each other’s needs,” she said, “so you needed someone like us to come in who could talk the language of both sides.”³⁸

Laser ranging is the most prevalent application for retroreflectors, but this innovative team at NRL developed a method to use them for laser communications too. In this application, the retroreflectors must behave like an on/off switch with a rapid switching rate that effectively digitizes laser light reflecting from them. These are known as modulating retroreflectors. The team worked with colleagues in NRL’s Optical Sciences Division—most notably Dr. William Rabinovich who with Gilbreath and several partners ended up as co-owners (with NRL) of the patent for the modulating retroreflector technology—to develop electrically controllable components that work like superfast shutters (in the 2 to 10 megabit-per-second rates) on the retroreflectors.³⁹

“This work opened us up to some new sponsors,” including the Office of Naval Research (ONR), with program managers who had an interest in investigating laser communication in maritime settings. This was one of the drivers for setting up an optical communications testing station at the NRL facility known as the Chesapeake Bay Detachment (CBD) in Chesapeake Beach, Maryland, with modulating retroreflectors set up on Tilghman Island, which is about 16 kilometers across bay waters from the laser-equipped CBD.⁴⁰

“There was a lot of work being done in laser communication at the time,” Thomas said. “It was around 2000 when you had the tech bubble. You had a lot of companies that had new ideas and new components for fiber communications.” Key here were developments in solid-state lasers, optical fibers, and other components that worked well with longer wavelengths than were possible to use before, including 1,550 nanometers (nm), for which the atmosphere is particularly transparent. More-

over, Thomas said, the 1,550 nm signal provides a safety benefit for the eyes, as the signal at this wavelength is absorbed by the eye fluid rather than the retina. With the CBD and Tilghman Island facilities, Thomas and her colleagues knew they were in a position to conduct a variety of experiments for characterizing the opportunities and limitations of laser communication in maritime settings.



Laser Comms. NCST engineers and partners conducted laser communications experiments using hardware such as the Dual Mode Optical Interrogator and a test bed with facilities at the Chesapeake Bay Detachment (CBD) and at Tilghman Island, 16 kilometers across the Chesapeake Bay from CBD.⁴¹

Reed described a scenario to concretize the Navy's interest in maritime laser communication. "Let's say you had a carrier group that was receiving and managing many kinds of data, and so if they wanted to push high amounts of data back and forth between the ships in the group, it could be done with laser communications techniques," Reed said, noting the laser system's relative immunity to interception or countermeasures compared to the more broadly cast RF signals. To move forward with laser communications in this context would require understanding how laser light behaves in different maritime conditions. "We had never rigorously explored that before," Reed said. "So that is where the interest by the Navy in research of laser comms over water comes from."⁴²

As their experiments showed, laser light propagates pretty well in the maritime environment. Unlike the ground, which heats up and cools down on a daily cycle, large bodies of water do not readily produce thermal gradients in the overlying air through which the laser light propagates. A result is fewer aberrations in the light passing over the water. "You do see weird phenomena, like inversions and ducting, where you have your optical beam splitting in multiple beams," Thomas said with interest and also as a cautionary tale. "So we learned all of these things while doing this applied research for ONR."

This work led the team to realize that it would be useful to have what became known as a Dual Mode Optical Interrogator (DMOI), which depended on engineering work in the 2005 to 2012 time frame by a Hawaii-based company, NovaSol.⁴³ With guidance from NRL's Rabinovich, the company's engineers developed laser communications terminals that had two modes. The primary mode sends a laser beam to a remote unit that uses a modulator to "write" data, say from a video camera, into the returning beam. In the second mode, two interrogator units up to 50 kilometers apart communicate with each other at gigabits-per-second data rates. As NovaSol puts it on its web site, "The object of this program is to develop a low powered optical laser link intended for a family of high bandwidth 'last mile' communication systems between ships, planes, and ground units."⁴⁴ The company delivered an "alpha unit" in 2004.

Two years later, Thomas and her colleagues installed a prototype laser comms unit on a Navy ship for testing during the Trident Warrior 2006 at-sea technology demonstration exercise, which unfolded between San Diego and Honolulu. "People had said you can't communicate over water, because the seas would be too rough for pointing and tracking systems, so we were classified as a high risk experiment," Thomas said. "At the end, we were rated in the top 3 of 103 experiments during the whole Trident Warrior exercise."⁴⁵ Despite this success, Thomas lamented, and despite stated needs by the Marine Corps of "line of sight" communication to augment the standard RF-based equipment, NCST's laser comms system was yet to be picked up for development into operational units for the Navy. Even so, the optics team within NCST continued working on fundamental studies of laser communication in the maritime environment, hedging that it will indeed play into a future Navy capability.

"Where we are now," said Thomas in 2014, "is that we have systems and we have transition agreements with the Marine Corps ... It has been a long road and a lot of research has gone into it. This is the first time in our optical comms area where we have a system that is really intended to be a prototype for something that could be fielded in quantity in a few years." The system in question, which includes tactical masts to extend line-of-sight distances, is for ground-to-ground communication, even in mountainous terrain, and unlike RF systems, is jam resistant.

"Our strength in NCST is our systems perspective, really understanding the needs of future users," Reed said. "We have an excellent perspective, because of the kinds of programs that come into NCST and because of the kinds of sponsors that NCST grew up with, and because of the interactions back and forth. I was fortunate to work on a lot of different kinds of programs at different levels of development. Then, in 2003, I went off and worked at the NRO for several years. I sat over there and saw what the real problems were. So when I came back to the lab, I was not guessing how NRL's technology could be used there. We have a lot of interactions like that, not just with NRO, but also with NOAA, DARPA, USAF and other organizations. We have temporarily detailed people away to these places, and they came back with a better understanding of what the needs are."

The same systems perspective pays dividends in-house as well. “Probably, a piece of everything going on at NCST is going on in collaboration with someone elsewhere at the lab, but each group brings a different kind of expertise there,” Reed observed, and within NCST are many engineers who understand how all of the pieces need to come together into a space system.

By way of example, Reed pointed to the Tether Physics and Survivability Experiment (TiPS), which was launched and deployed in 1996. The payload featured two ends attached by a tether, creating a flexible orbiting dumbbell of sorts (the system is described in more detail later). The leaders on the project, experts in RF and mechanical engineering, couldn’t “figure out a way to differentiate between the two ends,” Reed said. But NCST always has had a diverse range of skill sets in house, including optical engineering. “Just sitting around having a discussion, we knew that if we put different surface coatings on the two ends and used two different laser wavelengths that, boom!, they wouldn’t look anything alike to our laser ranging system. It is a simple and elegant solution, but if you don’t have the mechanical engineers and optical engineers having lunch over the table together, you probably are not going to solve the problem as quickly or as elegantly.”

Before the millennium gave out, NCST would take on another SDIO-sponsored project that would have an even higher profile than the LACE mission. Because NRL’s satellite engineering budget always had been in the minor leagues compared to NASA’s, NRL’s satellite engineers never really had the option of adopting the bigger, more expensive trend in spacecraft design and production. So when Daniel Goldin, Administrator of NASA for nearly a decade beginning in 1992, publicly announced that his civilian space agency was taking on a new philosophy of “faster, better, cheaper,” there was a familiar ring to it at NRL.⁴⁶

Emblematic of this design philosophy was the successful 1994 launch of the Deep Space Program Science Experiment (DSPSE), more familiarly known as Clementine.⁴⁷ Like LACE, the mission was funded under the auspices of the Strategic Defense Initiative Organization and that entity’s subsequent incarnation as the Ballistic Missile Defense Organization (BMDO).⁴⁸ Its purpose was to test whether an assemblage of new lightweight sensors, imaging technologies, and other components could enable a spacecraft to home in on distant targets. As an experienced satellite engineering facility within the military establishment and with a track record for successful, on-budget launches, NCST became a go-to organization for the SDIO.

“Clementine originated in a bar on I Street in Washington, DC, in September 1989,” recalled Dr. Stuart Nozette, Clementine’s Deputy Mission Director at BMDO, who years later would make headlines for a very different role he chose to play. In his leadership capacity at BMDO, however, he recalled that he “was talking to Dr. Pete Worden (working at that time at the White House National Space Council) and Geoff Tudor (then a Congressional staffer). We were discussing NASA’s approach to the Space Exploration Initiative (SEI) over drinks, when Clementine emerged as a way to



Clementine Double. A model of the Clementine spacecraft hangs in NRL's Building A59 as a trophy and reminder of the mission's enormous scientific and technological successes. (NRL photo B58Z8959.jpg)

flight-qualify recently developed technology and, at the same time, demonstrate to the civilian community the great strides made by the Department of Defense and SDIO in lower cost advanced space technology. I outlined the concept on a handy bar napkin and suggested the name as a way to discuss the concept.”⁴⁹ NCST would play a central role.



On-Napkin Concept. The concept for the Clementine mission to the moon and a nearby asteroid, Geographos, began during a discussion in September 1989 in a bar in Washington, DC, during which Dr. Stuart Nozette sketched the idea out on a napkin. (NRL photo 94-000182.tif)

The execution and payoff of the DSPSE mission would become celebrated in the annals of the U.S. space program. On January 25, 1994, a mere 22 months after Lieutenant Colonel Pedro L. Rustan, a mission manager with SDIO, asked NRL to come up with the details for DSPSE, Clementine was on its way on a mission with both military and scientific goals.⁵⁰ The military goal was to see how well an inexpensive, quickly engineered spacecraft might use new generations of sensors, communications technologies, and other equipment to zero in on and observe space-based objects. The long-term roster of objects included warhead-bearing ballistic missiles and other elements of an all-out Soviet attack. In this test run with the Clementine

mission, however, the objects included the moon, the Earth, and an asteroid called Geographos.

The scientific payoff would be the most detailed study of the moon up to that time, including a comprehensive mapping using nearly a dozen electromagnetic bands. Rustan and his leadership team, including Project Manager Paul Regeon and Project Scientist Dr. Donald Horan of NRL, and Project Manager Dr. Lyn Pleasance of Lawrence Livermore National Laboratory (LLNL), knew that the resulting data would comprise an enormous database about the moon's topography, geology, mineralogy, and geophysics. If all went well after that, the mission also would score the first ever rendezvous with a near-Earth asteroid. "The DSPSE spacecraft will come within 120 kilometers of Geographos as it passes the asteroid," Regeon predicted.⁵¹

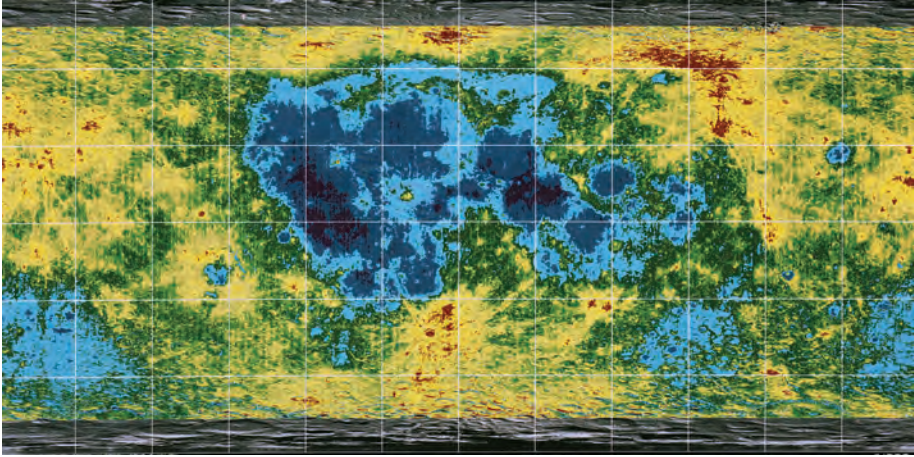
Besides BMDO, NRL, and LLNL, the Clementine team included NASA (for its Deep Space Network for satellite tracking), the Air Force (largely for carrying out the launch), the Jet Propulsion Laboratory (for the asteroid encounter), and nearly 50 private companies. The first overview paper about the mission, which appeared in *Science* magazine at the end of 1994, featured 35 authors with 20 distinct affiliations.⁵²

NRL began receiving funding to build Clementine in March 1992. And on December 30, 1993, the satellite was shipped to the Vandenberg Air Force Base in California. There, a team of engineers placed Clementine aboard a Titan II rocket. On January 25, 1994, the rocket soared into space. Within three months, Clementine already had completed an unprecedented mapping of the moon, including its dark side. That done, mission control engineers fired thrusters on Clementine so that it would leave lunar orbit and head off to fly by Geographos. Unfortunately, a software glitch caused the spacecraft to quickly consume virtually all of its thruster fuel. In addition to setting the spacecraft into a dizzying spin, the loss of the thruster function wiped away any chance of achieving the second goal of the mission—to intercept Geographos on August 31, 1994, and map the asteroid's surface.⁵³ Although hopes spiked in February 1995 when engineers were able to reestablish contact with the spacecraft and communicate with onboard computers, they were dashed again when it became clear the spacecraft would not respond or function well enough to salvage the asteroid mission.⁵⁴

Disappointing as that was, the Clementine mission became an instant classic of the Space Age. The mission was widely acclaimed in the media as a breakthrough demonstration of how space projects would be done in the future. *Popular Science* magazine ranked it as one of its top 100 achievements in science and technology for 1994.⁵⁵ A year after the moon data started pouring into NRL's makeshift mission control center in an unassuming rented brick building in Alexandria, Virginia—known by the Clementine team as "the bat cave" because it was so thick with dust and cobwebs when a real estate agent first showed it to them⁵⁶—even President Bill Clinton went on record about the mission's success. "The relatively inexpensive, rapidly-built spacecraft constituted a major revolution in spacecraft management and

design; it also contributed significantly to lunar studies by photographing 1.8 million images of the surface of the moon,” the President said.⁵⁷

According to Regeon, the program manager at NRL for Clementine, and col-



Moon Mapping. With multispectral imaging, the Clementine mission was able to map out compositional variations in the lunar surface with unprecedented detail. (NRL photo 95-000063.tif)

leagues who worked on the mission with him, the multispectral imaging data of the moon, which opened a new window on this natural satellite’s chemical composition, stands out as the mission’s most important orb-wide data. However, radar data from what was designated as “the Clementine Bistatic Radar Experiment” in the *Science* paper that described it revealed the most surprising result.⁵⁸

Dr. Gene Shoemaker of the U.S. Geological Survey and the overall leader of Clementine’s science team had a hunch that the moon’s poles, which appeared to have some regions that might be in permanent darkness, could harbor ancient water ice. With that impetus, Nozette devised “a bistatic radio frequency (RF) experiment to use the spacecraft transmitter to ‘peek’ into the dark areas of the moon,” recalled Dr. Paul Spudis of the Houston-based Lunar and Planetary Institute and a member of the Clementine team.⁵⁹ Of most interest to the eight Clementine team members who worked on this experiment, including NRL’s Dr. Christopher L. Lichtenberg, then the head of NCST’s RF Active Systems Section and an expert in radar data analysis, was the Aitken Basin at the moon’s south pole. After all, it is the deepest known basin in the solar system, bottoming out at a depth some eight times that of the Grand Canyon.

The transmitted radar signals, which echoed back from the massive basin to Earth-based receivers of the NASA Deep Space Network, did not exhibit the characteristics of solid rock, as most would have expected. Instead, the Clementine data confirmed Shoemaker’s hunch by indicating this sun-shielded basin likely contained ice. It was an exciting finding because the presence of lunar water of any kind opens the possibility that the moon may have harbored life at one time. Moreover, if water is available on the moon, the futuristic vision of building manned bases on the moon

and of converting the water into fuel for more far-flung expeditions becomes that much more realistic.

The planetary science community received additional evidence of the presence of water on the moon in 1998. Measurements of the moon's surface by instruments on the Lunar Prospector, which NASA launched on January 6, 1998, confirmed the presence of ice not only in the Aitken Basin where Clementine first had found signs of water, but also in craters on the moon's north pole. And since then, additional missions have heaped on evidence that the moon's poles bear stores of frozen water. Evidence in the form of the spectral signal for water's hydroxyl groups (oxygen-hydrogen units) was harvested in 2009 by NASA's Lunar Crater and Observation Satellite (LCROSS), which was deliberately crashed into the Cabeus crater near the moon's south pole to create a plume that could be instrumentally analyzed.⁶⁰

In one of the more bizarre side notes of NRL's history in space technology and its involvement with Clementine, Stuart Nozette would end up making headlines such as this one in the *New York Times*: "The Scientist Who Mistook Himself for a Spy."⁶¹ Several years after playing a lead role in the Clementine mission and being named as the lead author on some of the seminal scientific papers that came out of the mission, Nozette was convicted of selling government secrets to a person he believed to be an Israeli intelligence officer but was later revealed to be part of an FBI sting operation. He was sentenced in March 2012 to 13 years in prison.⁶²

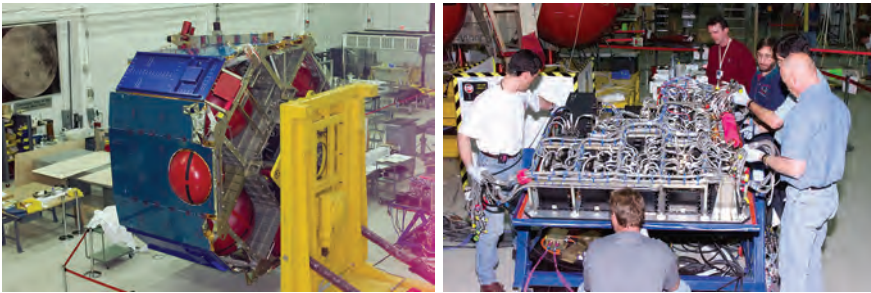
Even though NRO no longer was the primary funder for NCST as it had been in the 1960s, 1970s, and part of the 1980s, the NRL space technology cadre had managed, with new sponsors—including the very NASA that NRL's early space technology pioneers had helped to establish—to keep busy in the 1990s building a lot of hardware. But nothing was certain. With the collapse of the Soviet Union in 1991, the sense of urgency of the SDI/BMDO vision to protect Americans against a Soviet nuclear attack dwindled. Cooperation between the former Cold War adversaries was more the order of the day. At that time, the Russians were slated to provide a key component for the International Space Station: a tow-truck-like service module to intermittently reboost the station to higher orbits to compensate for the station's slow, relentless descent into lower orbits.

The service module, which would dock onto the station, also was supposed to execute large attitude maneuvers in case, for example, it looked like the station was on a collision course with a chunk of space debris. But Russia began to fall behind schedule; month-by-month in the mid-1990s, concerns were growing that Russia would not come through with their module in time for a needed orbital boost. And during a propulsion conference at which staff from NCST's Spacecraft Engineering Department (SED) got talking with some NASA cohorts, an idea for a Plan B that could circumvent the Russian booster was hatched.

"It was the 'Save the Space Station Mission,'" mused SED mechanical systems engineer Aaron Chilbert, though the official name for the fuel-heavy booster was Inter-

im Control Module (ICM).⁶³ In 1997, NASA authorized NCST to repurpose its Titan Launch Dispenser (TLD) to keep the International Space Station from prematurely reentering the atmosphere in what surely would be a spectacular fiery death throe. As mentioned at the beginning of this chapter, the TLD itself derived from a booster module—the Shuttle Launch Dispenser (SLD)—that NCST had previously designed for use in the Space Shuttle program. So the Multiple Satellite Dispenser programs begat the SLD, which begat the TLD, which begat the ICM.

It was a challenging, fast-turnaround mission, but within the realm of the doable for the seasoned NCST satellite engineers. It had its cinematic moments too. “At one time, we had the head of NASA, Daniel Goldin, here with the head of the Russian Space Agency, both doing a kind of post Cold War showdown” around this booster episode, Chilbert recalled. NCST leadership was asked by Goldin to give his Russian counterpart a tour of the facilities, including the cavernous A59 where many a classified program had unfolded, and some were still. “We had to put some stuff away so the Russian guys couldn’t see what else we were doing,” Chilbert recounted. Referring to the backup service module, he added, “You could almost hear our guys saying ‘My hardware is almost ready; what are you guys going to deliver.’ It was a surreal moment.”⁶⁴



Space Tug. When there had been some question of whether Russia would come through with a promised propulsion unit to intermittently re-boost the International Space Station to higher orbits to compensate for its slow but steady descent, NCST was tasked to build what amounted to Plan B—the Interim Control Module (ICM), shown here in one of the high bays of Building A59. Shown at work on the ICM’s complex plumbing are (from left to right): Brian Whalen; a NASA tech (squatting); Scott Chappie; John Gambert; Mike Roe; and Paul Stencil. (NRL photos B58Z3821 (1).jpg and B58Z3177.jpg)

It also was quite a real moment of technocratic politicking. “I understood that the main reason that Goldin and the Russians came over to the lab was because the Russians didn’t believe that the U.S. had existing hardware that could replace their service module,” said Art Collier, whose previous role as the Special Projects Office (SPAWAR 004-5) director from 1986 to 1990⁶⁵ placed him in the loop on the technology underlying the ICM. “They wanted the U.S. to provide them with additional funding to accelerate their development.”⁶⁶ The U.S., rather than taking the step of preparing a backup service module, would have preferred the Russian engineers to come through in time with the service module they had promised for the ISS program. But if it was going to be Plan B, the Russians would have to help the NCST team design the back-

up so that it would work with Russian hardware on the International Space Station.

The ICM project became a high priority. Recalled Collier, “We got to work with the astronauts in getting things ready for the Shuttle,” which would carry the ICM to the Space Station. Additionally, there was a team of Russian engineers integrated into the lab work force to oversee the design of the docking mechanism that would have to mate with the Russian-provided docking port on the Space Station. All the while, the Russians’ colleagues back home were still at work on the original service module. We “were pretty much within a year of delivery when NASA finally said, ‘Alright you can stand down. Put it in storage. The Russians have delivered their Service Module.’”⁶⁷

The nearly completed ICM was destined to become like a curio in a natural history museum; it was designed, built, never launched, and instead took up residence in its own plexiglass display case in A59. The cancellation of the ICM took a toll on the department’s head at the time, mechanical engineer H. Edward Senasack, and his ICM team. Senasack joined the lab in 1970 after earning a mechanical engineering degree from the University of Maryland, but he had long been aware of NRL because his father worked in the lab in the supply services division. “If you want to work at the Naval Research Laboratory, you should work for Pete Wilhelm,” Senasack recalled his father telling him, and he managed to follow that advice.⁶⁸ The ICM cancellation came as a blow. “[Ed Senasack] had 200 people working on the ICM and suddenly NASA called up and said ‘we’re done,’” recounted Schaub, who would succeed Senasack as head of the Spacecraft Engineering Department and then later, in 2016, would succeed Pete Wilhelm to become director of the Naval Center for Space Technology.⁶⁹ “It is hard when you have to tell someone they no longer have a job and he struggled with that.”⁷⁰

Schaub’s professional trajectory in the 1990s also reflected how the relationship between NRL and the National Reconnaissance Office had evolved. During the last years of the millennium, from 1994 to 1998, Schaub was detailed out to the NRO in Chantilly, Virginia, where he would bring NRL’s and NCST’s institutional knowledge into the sophisticated business of specifying requirements for new classified satellite systems and then oversee contractors and others who would be charged in designing, building, and delivering the hardware. Many NCST engineers, including Aaron Chilbert and Chris Dwyer, would do stints at NRO headquarters where they would serve as advisors, consultants, and contract and acquisition managers.

The NRO-NRL relationship, once dominated by the former Program C’s ELINT satellite programs, GRAB and Poppy, extended in the 1990s beyond the detailing of lab personnel to NRO headquarters. Although contractors were by then building the production models of NRO’s satellites, NRL and NCST got into the game of building smaller spacecraft under NRO sponsorship to investigate specific new technologies and concepts. One of these—a purely experimental mission—was the Tether Physics and Survivability (TiPS) experiment, which was deployed from a Titan IV booster on June 20, 1996. The charge of the nearly two dozen NCST engineers and support per-

sonnel assigned to the mission was to design, build, and deploy a small satellite with two parts coupled with a tether in order to investigate how tethered systems behave in orbit and how long they can survive. TiPS lasted 14 years. Also on the minds of TiPS planners was the possibility that such a system, if deployed with an electrically conductive tether, could generate power for a spacecraft with the current induced in the tether as it swept through Earth's magnetic field.

Several hours after the TiPS satellite separated from a host vehicle, a braided tether (made of Spectra 1000 fiber, a polyethylene fiber said to be stronger than steel, over



Tether Tests. With its two components tethered together, TiPS—depicted here in the mission's logo—tested the behavior and survivability of structures that could be designed to generate power as the tether moved through electrically charged regions of orbital space.

acrylic yarn)⁷¹ connecting its two end masses, dubbed Ralph and Norton after the comedic pair of the 1950 TV series “The Honeymooners,” unreeled a length of about 2.5 miles (4 kilometers).⁷² James Winkler, who designed the electrical harness for managing power distribution to all the system's components, credits TiPS Program Manager Bill Purdy with coming up with the comedic monikers.⁷³

The 83-pound Ralph contained all the electronic components, among them a NASA-supplied telemetry system and temperature sensors, as well as a spool bearing 12 pounds of string-thick tether. A globally distributed network of laser-based tracking stations, including one at NCST's own Midway Research Center in Virginia, provided sub-meter-resolution tracking and range data for Ralph and Norton (the latter weighed in at about 23 pounds), as well as measurements of a pendulum-like motion (libration) about the center of mass.

“Tethered systems are a new and relatively untested space technology,” remarked Robert Towsley, TiPS Systems Engineer at NRL, at the time of the deployment. How well do tethers unreel from their spools? Once deployed, how well do they remain intact? What kinds of motions do they exhibit? These were among the basic questions that Towsley and the TiPS team, and their NRO sponsor, had in mind. “From a survivability aspect, TiPS' tether is susceptible to space debris damage,” noted Shannon Coffey, Mission Operations Manager for TiPS for NCST. “The tether, roughly 2 mm [millimeters] in diameter, can be severed by a particle as small as 1-mm travelling at a relative velocity of 14 km/s [kilometers per second] (31,318 mph),” added Purdy.⁷⁴

As the reel unwound like fishing line, Ralph and Norton separated at a relative velocity of approximately 5.1 meters per second (16.7 feet per second). The passive



Midway Research Center. The three 18.2-meter-diameter tracking antennas at NCST's Midway Research Center, located in Stafford County, Virginia (and with associated tracking facilities in Palo Alto, Guam, and elsewhere), can transmit precision test and standardization signals to on-orbit satellites for such jobs as performance validation and verification, calibration, and anomaly identification and resolution. MRC also hosts an Optical Test Facility, built several years after this 1997 photo, for developing optical communications techniques and ground-to-air laser-based tracking capabilities. (NRL photo 98-000006(16).jpg)

deployment scheme depended on a mechanical system, including spring cartridges, to unreel enough tether and to generate enough separation between Ralph and Norton that the gravity gradient phenomenon, which NRL's space technology engineers had been exploiting for orientating their spacecraft since the 1960s, could do the rest. "The initial separation energy was designed to deploy about 2 km of the tether, at which time gravity gradient forces assisted to unwind the remainder," according to an NRL-issued description.⁷⁵

Retroreflectors on the exterior surfaces of both Ralph and Norton enabled the TiPS team to conduct long-term passive monitoring of the tethered system using the global satellite laser ranging network.⁷⁶ They were able to distinguish between the two end masses by cleverly coating the retroreflectors of Ralph to reflect only one of the two transmitted laser wavelengths, while the uncoated retroreflectors on Norton reflected both wavelengths.

Towsley noted that the data from TiPS would help "to verify and improve understanding of the physics of tethered systems in space as well as the mathematical models" developed to describe them, and provide information for engineering and development of future tether systems.⁷⁷ Tether-based systems indeed have remained part of the thinking and portfolio of NCST. In the 2010 time frame, for one, Pete Wilhelm, then still the NCST director, and others at NCST were developing an ambitious scheme using tether-based systems to help clean up the vast amount of space debris that has built up in low Earth orbit since the early days of the Space Age. The idea is

that spacecraft with robotic arms and others means of grappling space debris would be on the ends of conductive tethers that would generate electrical power as they moved within the ionosphere and other electrically charged areas of the low Earth orbit. This electrical power, in turn, would enable the system to maneuver to and grab onto different pieces of space junk and then usher each one to a much higher “parking” or “graveyard” orbit where the debris would be out of harm’s way of useful satellites in lower orbits.⁷⁸

The launch of TiPS in 1996 occurred smack in the middle of Schaub’s detail at NRO headquarters where he became involved with NRO Launch 8 (NROL-8), which included another tether experiment. The mission was the first of only a few satellites that NRO has ever announced to the public; Schaub even ran an NRO press conference, a rarity, to tell reporters about the project. Known rather vaguely as Space Technology Experiment, or STEx, the spacecraft, which was launched from Vandenberg Air Force Base on October 3, 1998, carried about 20 technology experiments, two of which were built and delivered by NRL.⁷⁹ Lockheed Martin was the prime contractor in overall charge of producing the satellite. This placed Schaub in a funny situation. “I am an NRL detailee out at NRO and then NRL became a supplier of mine,” said Schaub. “So I had to walk that fine line. I had to make sure that NRL produced things that they were responsible for.”⁸⁰

One of the NRL experiments on the STEx mission, the Electric Propulsion Demonstration Module (EPDM), featured a device that generated electrically charged ions, which were then shot out of a nozzle to produce small but sustained and highly controllable propulsion. In space, tiny amounts of thrust maintained over a long period of time ultimately can generate spacecraft speeds that exceed what can be obtained with enormous but short-lived thrusts from traditional solid or liquid fueled rocket engines.

The other NRL experiment aboard STEx was the Advanced Tether Experiment (ATEX), a follow-on to the TiPS payload. ATEX consisted of a box-shaped compartment hosting a reel of carbon-fiber-reinforced plastic ribbon attached on its free end to a gold-foil-wrapped panel with corner reflectors for high-precision, laser-based tracking. Once the assemblage was deployed in orbit, the ribbon was supposed to unfurl more than 6,000 meters. But Murphy’s Law managed to intervene: only 18 minutes after the tether began unfurling, the mission ended suddenly in failure when the tethered pair was unexpectedly jettisoned from the STEx spacecraft.⁸¹ Only 22 meters of the ribbon had been deployed. To protect the overall STEx platform and the many other payloads it carried, ATEX was designed with an automatic jettisoning mechanism that would be triggered if the tether began to stray from its expected departure angle. A subsequent analysis by a trio of engineers in NCST’s Spacecraft Engineering Department (SED) determined that excessive tether slack triggered a sensor reading exceeding an “out of bounds” limit, which amounted to an unacceptable risk to the overall STEx mission. “This sensor then produced the jettison command,” concluded

SED engineers Stephen Gates, Stephen Koss, and Michael Zedd.⁸² It was a disappointing, show-stopping result for the experiment, though Wilhelm and his many NCST colleagues view failure in the course of new space technology developments as a success of sorts that can help steer engineers toward more reliable technology down the line.

Schaub returned to NRL in 1998 as Associate Superintendent of NCST's Spacecraft Engineering Department. That was just in time for him to help manage the lab's



Ion Thrust. NCST engineers prepared this Electric Propulsion Demonstration Module (EPDM) for testing on an NRO technology-testing platform known as Space Technology Experiment (STEx). Referred to as a Hall-effect thruster, it works by ionizing the propellant and then accelerating the ions to create thrust. (NRL photo EPDM.tif)

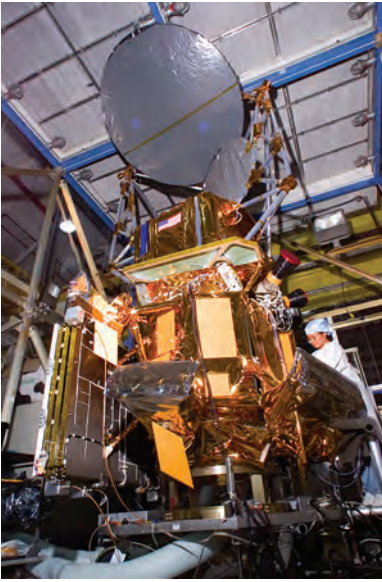
role with Windsat, an ocean surface monitoring satellite project, which was funded by the Navy and was in deep trouble. Windsat was a proof-of-concept mission for a capability that would be of great tactical and operational importance to the surface Navy.

At the time of Schaub's return, NCST and the Spacecraft Engineering Department were, in Schaub's words, "in deep dung." The Windsat program, which was developed under the auspices of the Department of Defense-wide Space Test Program, was over budget and behind schedule. There was a lot of external sponsor pressure coming in that was felt all the way up to the office of NRL's Director of Research, Dr. Timothy Coffey, to make things right.⁸³ Recalled Schaub: "With a finger in my chest, I was told, 'You have the most program management experience of anybody here; your job is to clean up this mess.'"

"The issue, when you are developing something for the first time, is that it sometimes is more challenging than you originally envisioned," Schaub noted. "But your customer community is not used to operating in that environment. They expect you to be experts and to be able to predict at all times what it is going to take to design and build [the spacecraft], and to be on schedule and on budget."

It took two years, major changes in managerial tactics, and a huge team effort at NCST, but the ship was righted. "Windsat was a near death experience for us," Schaub

said. “It was a nightmare that turned into a huge success,” added Senasack, who was Schaub’s immediate boss before Schaub took over the supervisory role at the SED.⁸⁴ The technical aspects of the mission were formidable. But in some ways, these were the easier challenges of the mission to tackle. It was the subtler successes of improving communications and relationships among the stakeholders in the Department of Defense, Navy, and NCST that also enabled Windsat to enter its orbital perch.



Windsat Win. A saga between its conception, launch, and unexpectedly long and successful operation, Windsat provided data about conditions at the sea surface with a spatial and temporal resolution that is sufficient for real-time naval operations. (NRL photo B58Z9072.jpg)

From a technical standpoint, Windsat was a proof-of-concept project to demonstrate the ability to measure ocean-surface wind speed and direction—the “wind vector” in more technical parlance—with spaceborne passive microwave remote sensing. “The global ocean-surface wind vector is essential information for short-term weather forecasts and warnings, nowcasting and climatology and oceanography studies in both the civilian and military communities,” wrote NRL antenna engineer Wendy Lippincott, NRL colleague Dr. Peter Gaiser of the lab’s Remote Sensing Division, and several contractor partners.⁸⁵

Wilhelm points to an additional important application, one that he said came to his attention as he was hosting a tour of NCST facilities for a Vice Admiral who had a say in NCST’s future funding. “In a previous job, he’d been in charge of the cruise missiles that the Navy launches,” Wilhelm noted. The tour included a stop at a model of the Windsat spacecraft in Building A59. Wilhelm recalls the Vice Admiral saying, “That wind-speed direction data, you know, over the path that my missiles have got to fly, is absolutely essential. Got to have that.” When he saw the model, Wilhelm recalled, he said, “Man, that’s good stuff.”⁸⁶

The science underlying Windsat emerged from more than 30 years of basic investigation in NRL’s Remote Sensing Division in collaboration with other government

agencies and universities into how wind conditions at the ocean surface influence the ocean's natural microwave emissions, which are induced by the wind-water interaction.⁸⁷ Weak as the wind signals were, NCST engineers and their partners worked through challenges to measure those emissions with a passive space-based sensor called a microwave radiometer.

"You talk about a difficult instrument to build," Wilhelm quipped. "The Windsat is probably the most difficult of anything I've ever heard of in the RF domain."⁸⁸ That's because the spacecraft's radiometer would have to detect and accurately measure the wavelengths and intensities of extremely weak microwave signals emanating from the ocean surface and do so with a resolution fine enough to have operational and tactical value. Moreover, the instrument had to make these measurements while viewing a pixel of the ocean for only a few milliseconds as the satellite flies over, yet still be capable of characterizing subtle amplitude and polarization features of the microwave emissions. Simulation and engineering studies showed this could be achieved with 11 "feed horns" of different sizes that could pick up specific key ranges of microwave radiation, and a main dish reflector to shunt emissions from below into the feed horns. All of this and more technical capability had to be packaged within stringent size and weight constraints. Also, any reflections and interfering emissions from the spacecraft itself had to be minimized, lest the raw data be too confusing for the algorithms and raw-data-to-wind-speed models (that Gaiser and his colleagues developed) to make any sense of.

Regardless of these challenges, Wilhelm said, "we've done it, it works, and nobody else can say that."⁸⁹ Working with Gaiser and other remote sensing specialists at NRL were many NCST space technology engineers with expertise in antenna design, electrical engineering, and a wide range of other skill sets. Lippincott, an RF engineer with NCST, for example, was tasked with overseeing the antenna modeling that would help zero in on the actual design to implement for the spacecraft. "It is a complicated system that requires modeling antennas that are going to look down to the Earth and measure the ocean surface, so it involves very complicated equations," she noted.⁹⁰ "They told me I was going to do this and I was like, 'You want me to what?' At first, I did not understand it all, but I plugged away at it and it worked out. I was the one who had to tell them where to place everything."

By collecting emission data and running it through well-validated models linking microwave emissions to the wind conditions that elicit them, Gaiser and his colleagues, led by Mike Bettenhausen, managed to hone methods for extracting wind vector data—direction and speed—from the microwave data with the necessary spatial and temporal resolution. Gaiser became the Principal Investigator for the Windsat spaceborne polarimetric microwave radiometer demonstration project, which is to say, the technical heart of Windsat. He worked closely with partners including Lippincott, Program Manager David Spencer, and other NCST engineers who designed, built, and tested the spacecraft in preparation for its 2003 launch.⁹¹

Once data started coming in from Windsat, others realized that wind vectors were just one geophysical feature that the spacecraft could monitor. “The same microwave channels that you needed to come up with wind vector data would give you some other products that have become really important to the Army and Marine Corps,” Schaub pointed out. One example is the ability to measure the amount of moisture in soil, an indicator of how well, for example, tanks and other military vehicles will fare in a particular real or potential military zone. “If you were planning a mission and you really wanted to know if you are going to get your vehicles stuck in mud, this would be important data at your fingertips.”

Windsat was a primary payload aboard the Air Force Coriolis satellite, and it was sponsored jointly by the Department of Defense Space Test Program (STP) and the Navy (SPAWAR Command). It was supposed to have lasted only three years after its January 2003 deployment. Instead it has remained in orbit, where, noted Schaub, in addition to serving the Navy, it has been providing operational data to the National Hurricane Center, the National Typhoon Warning Center, and others.⁹²

Crucial to the solution to pulling the Windsat program out from the budgetary and scheduling muck it had entered in the years before it was launched was to establish better and more frequent lines of communication between the NCST satellite-builders and its partners and sponsors within the Department of Defense, Navy, and other members of the National Polar Orbiting Environmental Sensor System (NPOESS) Integrated Program Office, which oversaw the mission. Noted Schaub: “It takes two things to communicate: someone on the transmitter and someone on the receiver. We had to fix both sides. We initiated monthly program reviews. When they didn’t attend, we sent them PowerPoint slides in which one would say ‘unless we hear from you, this is how we are going to proceed.’ We turned that program around and were able to successfully manage expectations.”⁹³

Also important was for the NCST team to appreciate that their business of satellite engineering and satellite building, with its inherent delays and budget surprises, does not jibe well with the budgetary cycles and other administrative constraints of customers who are not themselves in the business of space technology but seek satellite-based capabilities. “If you are in some fiscal year, and in the first few months you develop major setbacks in a program, and you suddenly tell your customer you need 5 million dollars more this year to stay on schedule, unless your customer is just rolling in dough, which he usually is not, that is a major problem,” Schaub explained. “That is what happened with Windsat.” In the early decades of space technology at NRL, when NRO was the primary sponsor, money was less of an issue.

“We designed Windsat for a one-year life, with a three-year goal, and right now we are in its tenth year of successful operation,” Schaub said with a sense of triumph in an interview in 2012. “It is still healthy and, knock on wood, it is still performing today.”⁹⁴ As of 2018, Windsat was still in operation.

As has always been the case, the space technology business remains precarious, even after successes like Windsat. At NRL and NCST, tidal forces from upper eche-

lons in the Navy, Department of Defense, and other government bodies always have been at work and they can just as soon give as well as take.

A case in point was the planned follow-on to Windsat, which was part of the NPOESS program and jointly run by its partners by way of the NPOESS Integrated Program Office. “As a result of our success on Windsat, we were eventually given the job of flying MIS—the Microwave Imager Sounder,” noted Schaub. “We were basically asked by the NPOESS program office to make an operational version of Windsat—add some additional capability—and transition that to industry so that they could build it in the future.”

But things had gone badly with the Air Force’s contract with Boeing for the Conical Microwave Imager Sounder (CMIS), whose requirements were similar to those of Windsat and for which Windsat was meant to serve as a “risk reduction” payload.⁹⁵ Much to the NRL participants’ chagrin, Schaub noted, the Integrated Program Office overseeing the CMIS collaboration had not adopted some hard lessons learned regarding the transitioning of government-driven space projects to industry partners. Congress decided to cut the country’s losses on the NPOESS program and directed that the CMIS contract be canceled.

It was a blow to the NPOESS program, but one of the leaders for the Defense Department’s part of the program at the time, Colonel Susan K. Mashiko (later a Major General and Deputy Director of NRO), was unwilling to let the project go entirely. She knew about NCST’s capabilities and asked the lab to give it another go. Schaub and his team estimated that they could deliver a launchable CMIS-equivalent payload for under the \$250 million already spent. After all, the team had learned important technical and managerial lessons with Windsat. It took some guts, but Colonel Mashiko pushed hard to give the job to NCST and slightly renamed the payload as the Microwave Imager Sounder (MIS).

The NPOESS Integrated Program Office initiated the MIS sensor project at NRL in July 2008. In 2009, the lab—with primary participation from the Remote Sensing Division and NCST’s Spacecraft Engineering Department—successfully passed the major milestone of the System Requirements and Design Review.⁹⁶ And in early April 2010, the team passed the IPO’s next milestone, the Preliminary Design Review.⁹⁷ In 2010, the NPOESS program was canceled, but the MIS instrument was slated to fly on the follow-on program, the Defense Weather Satellite System (DWSS). However, the task to deliver MIS was fated for a premature ending when on December 31, 2011, President Barack Obama signed the 2012 Defense Authorization Bill that zeroed out funding for DWSS,⁹⁸ an action that thereby shelved MIS ... almost literally. The payload ended up sitting idle in Building A59, though NCST was funded to remain in the loop so that it could help the Air Force develop requirements and reduce risk for its space-based microwave sensor needs in the future.⁹⁹

“Cancellation is an occupational hazard” in the satellite business, noted Schaub. In NCST’s Spacecraft Engineering Department alone, there are 150 civilian employ-

ees working with at least another 100 experts in contracting firms. It is a managerial challenge to keep such a workforce motivated and to prevent them from getting discouraged when programs get canceled, as they do, even after large, highly skilled teams have spent years and even hundreds of millions of dollars or more. “I lose sleep over this,” said Schaub.¹⁰⁰

This is why NCST’s push to diversify its sponsor base, beginning in the 1970s when NRO was moving toward contractors to build its operational satellites, had been so crucial for NCST’s long-term viability and competence in building satellites. In the mid-2000s, as Windsat was getting its first years under its belt, the Air Force and the Defense Advanced Research Projects Agency (DARPA) needed a contingent of NCST payload-builders to construct what was unceremoniously dubbed the Upper Stage. It was a sophisticated propulsion system for precisely transferring a set of small satellites into their own individual geosynchronous orbits from an initial geosynchronous trajectory achieved with the main booster vehicle. The Upper Stage, also known as the NRL Precision Orbital Transfer Vehicle,¹⁰¹ was akin to the MSD, or Multiple Satellite Dispenser, which Wilhelm had originally designed for placing satellites initially clustered on a single framework into specific orbits. As such, the Upper Stage was a satellite unto itself, replete with its own ability for autonomous operations and so with its own processing, software, and communications systems.¹⁰² Its role in the DARPA-sponsored mission was to deposit several classified satellites of a program dubbed MiTEx into specific orbits. The government revealed very little about the mission, which gave reporters a license to speculate or to find sources that would.¹⁰³

The NCST Upper Stage team got started on the project in late 2003. Within two years, the team had completed design, analysis, and integration phases, as well as preliminary tests. Those included mission simulations and compatibility exercises with ground station facilities—in particular, NRL’s Blossom Point and the Air Force’s Satellite Control Network (AFSCN)—for command, control, and telemetry. Vibration, thermal, acoustic, and other tests to ensure flight worthiness followed with good results, enabling the NCST team to ship the vehicle and supporting ground and mechanical equipment by truck to Cape Canaveral by December 2005.

There, another battery of tests proved the health of the Upper Stage, but due to a delay in the readiness of the Delta II launch vehicle, that forward momentum had to be cut off for a time, with the Upper Stage going back into its shipping container and stored on-site. NCST participants described some of the final preparations for the Upper Stage (U/S) this way:

“NRL propulsion engineers, working with CCAFS [Cape Canaveral Air Force Station] contractor personnel, precisely loaded the mono methyl hydrazine (MMH) and nitrogen tetroxide (NTO) hypergolic propellants into the U/S fuel tanks. Following fueling, the small satellites were installed by NRL engineers and technicians on the top deck of the U/S. The integrated stack, known as the Space Vehicle (SV), was ... installed on the Delta II third stage, which had been spin balanced separately. A

large modular protective canister was installed around the integrated third stage and SV. Very early one morning two weeks before launch, this canister was slowly towed to Launch Complex 17A and hoisted on top of the rest of the Delta II rocket. The protective canister was removed, and final preparations of the SV were performed. These preparations included removing covers from sensitive surfaces, installing arming plugs, and performing pre-launch functional tests.¹⁰⁴



Orbital Delivery. On June 21, 2006, the multi-payload mission, MiTeX, along with an NCST-built orbit-delivery system known as the Upper Stage, rockets toward orbit. Meanwhile, mission operations engineers at NCST's ground station in Blossom Point, Maryland, monitor the mission during the "main burn" phase. (NRL photos 8P584673.jpg and DSC_0032.jpg)

On June 21, 2006, the rocket finally launched and inserted the satellite-laden vehicle into a preliminary geosynchronous orbit. Evidence of success came through to the Blossom Point (BP) ground station in Maryland by way of signals initially picked up by the AFSCN's Diego Garcia Remote Tracking Station in the central Indian Ocean. From that point, NCST staff at BP undertook all command and control for the mission, though tracking and telemetry data were collected at both BP and the AFSCN facilities. With NCST-developed orbit determination software, which was important for planning maneuvers and pointing ground antenna, it took four days of operations for the Upper Stage to insert its MiTeX satellite payloads into predetermined geosynchronous orbits.

The mission proved out a roster of new technologies, including new catalyst-based thrusters, lightweight all-titanium propellant tanks, and a low-cost, high-performance star tracker for attitude control. "This experimentation and these technologies enable such missions as autonomous maneuvering, transfer of secondary payloads, and orbit plane changes," the NCST engineering team concluded in a summation they wrote up for NRL's annual review in 2007.¹⁰⁵

Despite NCST's successes at diversifying its sponsor base for building payloads, and not just prototypes to help industry contractors build the real birds, the satellite-building activity at NCST has been on a steady decline since the end of the

Poppy program in 1977. This shows up with stark clarity on NCST's list of satellite and payload launches, which is dense with almost annual launches—many of them multiple-payload launches—between 1960 and 1977. Of the three declared payloads prepared for launch in the 1980s, one failed and two made it into orbit (where they would end up opening an important new business in ground-deployed technologies for NCST). Thereafter, the frequency of launches with NCST payloads settled into one every few years. Most of these have been squarely in the category of technology tests and validations, rather than full-blown operational payloads. The most recent full payload that NCST engineers built, tested, and launched was Tacsat-4, an experimental communications satellite supported by the Office of Naval Research that made it into orbit from a launch pad in Kodiak, Alaska, on September 27, 2011.

The trend toward fewer full-payload projects has been unfolding ever since NRO's Program C manager, Rear Admiral Tom Betterton, sounded the alarm to then NCST director Pete Wilhelm and his space technology engineers that they were going to have to find new sponsors for their R&D work as the NRO shifted its SIGINT satellite production from NRL to aerospace contractors. It has been a theme and source of institutional angst, and also a catalyst for change and innovation, for NCST and NRL leadership ever since. Dr. John Montgomery, an NRL veteran with a wry sense of humor who earned his top-notch engineering reputation in the arena of electronic warfare before he succeeded Dr. Timothy Coffey in 2002 to become the lab's Director of Research until his retirement in 2016, was reminded of the precariousness of the satellite business with the Microwave Imaging Sounder cancellation in 2010. He reiterated to Wilhelm, Schaub, Dwyer, and the entire NCST staff that they needed to redouble their efforts to identify and secure sponsors and projects that would extend NCST's decades-long history of contribution to the U.S. space program.

"We are one of the very few places left within the government where we have all of the skills, knowledge, and abilities within the civil service to design, build, and test spacecraft and instruments," says Schaub.¹⁰⁶

NCST still has "unparalleled capability in the full spectrum in space stuff, from the orbiting peripherals [satellites] on through the information and distribution and utilization and analysis of information," reiterated Rear Admiral Betterton in an interview.¹⁰⁷ But they don't have a dedicated sponsor any more like NRL's first generations of space technologists, he continued. NCST engineers now have to be more entrepreneurial, more in the loop on how their skill sets and know-how can help other agencies throughout the government apply space assets to their purposes, and more capable of forging the connections and sponsorships that it always has taken at NRL to get a single ounce of hardware into space.

It has become an imperative to work for more than one customer at a time, which means managing many large and small programs at a time, and diversifying the work portfolio to degrees that the elders of NRL's space technology lineage could not have

imagined in their own primes. When Betterton started to let out the news that NRO would no longer be there as it had been in the past, some within the NRL space cadre got over their denial quickly and viewed the imminent change as a great opportunity to think of satellites and payloads merely as the highest flying parts of what the term “space technology” denoted. In this new context, satellites were indeed the “orbiting peripherals” of much larger, complex, and technologically diversified systems with subsystems and components that would have places on the sea, land, and air all over the planet. As the NCST engineers saw it in the 1990s, it was time to make sure that the national satellite assets above could be used to discern in near-real-time the expanding range of threats below, and provide useful data and usable systems to the warfighters, the national defense community, and civilian emergency responders who could do something about those threats.

¹ John Schaub, interview with author, February 28, 2012.

² A short history on the firm’s website specifies that the Martin Marietta Corporation formed in 1961 when American-Marietta merged with the Glenn L. Martin Company to become “a leader in aerospace, cement, aggregates, electronics and chemicals”; <http://www.martinmarietta.com/Corporate/history.asp>.

³ Peter Wilhelm, interview with author, May 17, 2013.

⁴ John Schaub, interview with author, February 28, 2012; see also James Winkler, unpublished memoir shared with author, 2012, p. 79.

⁵ James Winkler, memoir, p. 74.

⁶ John Schaub, interview with author, February 28, 2012.

⁷ Art Collier, personal correspondence with author, April 22, 2012, and January 29, 2013.

⁸ John Schaub, interview with author, February 28, 2012.

⁹ James Winkler, memoir, p. 79.

¹⁰ “LACE,” Naval Research Laboratory Publication 199-8105, October 1991.

¹¹ <http://setas-www.larc.nasa.gov/LDEF/>.

¹² John Schaub, interview with author, February 28, 2012.

¹³ James Winkler, memoir, p. 73.

¹⁴ <http://ncst-www.nrl.navy.mil/HomePage/LACE/LACE.html>.

¹⁵ D.E. Horan, R.E. Perram, and R.E. Palma, “The NRL Lace Program Final Report,” NRL Report NRL/FR/8121-93-9565, Naval Research Laboratory, Washington, DC, August 27, 1993.

¹⁶ John Schaub, interview with author, February 28, 2012.

¹⁷ <http://ncst-www.nrl.navy.mil/HomePage/LACE/LACE.html>.

¹⁸ Don Horan, “NRL’s LACE satellite re-enters atmosphere,” in *Abstracts*, Naval Research Laboratory, September 11, 2000.

¹⁹ John Schaub, interview with author, February 28, 2012.

²⁰ Horan et al., “The NRL Lace Program Final Report,” pp. E-1, 5–6.

²¹ Chris Dwyer, interview with author, February 9, 2012.

²² John Schaub, interview with author, February 28, 2012.

²³ Chris Dwyer, personal communication, February 13, 2012.

²⁴ John Schaub, interview with author, February 28, 2012.

²⁵ Horan, *Abstracts*, September 11, 2000.

²⁶ John J. Degnan, “Thirty Years of Satellite Laser Ranging,” presented at the Ninth International Workshop on Laser Ranging Instrumentation, held November 7–11, 1994, in Canberra, Australia, accessed at http://ilrs.gsfc.nasa.gov/docs/ilrw09_vol1.pdf.

- ²⁷ Michael J. Vilcheck et al., “Overview of the NCST’s New Optical Research Facility,” IEEE Aerospace Conference (2001), <http://dx.doi.org/10.1109/AERO.2001.931379>.
- ²⁸ Phone interview with Linda Thomas, September 20, 2013.
- ²⁹ Interview with Anne Reed and Linda Thomas, June 4, 2014.
- ³⁰ Interview with Anne Reed and Linda Thomas, June 4, 2014.
- ³¹ <http://www.nrl.navy.mil/media/news-releases/2005/project-ande-assembly-and-testing-near-completion-at-nrl-for-fall-delivery-to-nasa> and <http://www.nrl.navy.mil/media/news-releases/2009/nrls-ande2-launches-aboard-sts127>.
- ³² See, for example, <http://www.nasa.gov/centers/wallops/CARE.html>.
- ³³ NRL Press Release, “Space Station Astronauts Launch SpinSat; NRL Starts Getting Data,” January 12, 2015, <http://www.nrl.navy.mil/media/news-releases/2015/space-station-astronauts-launch-spinsat-nrl-starts-getting-data#sthash.d7QVDa4Z.dpuf>; NRL Press Release, “With SpinSat Mission, NRL Will Spin Small Satellite in Space with New Thruster Technology,” <http://www.nrl.navy.mil/media/news-releases/2014/with-spinsat-mission-nrl-will-spin-small-satellite-in-space-with-new-thruster-technology#sthash.ptln0Iqe.dpuf>.
- ³⁴ Interview with Anne Reed and Linda Thomas, June 4, 2014.
- ³⁵ Interview with Anne Reed and Linda Thomas, June 4, 2014.
- ³⁶ Interview with Anne Reed and Linda Thomas, June 4, 2014.
- ³⁷ See Interview of Dr. Carroll O. Alley by Joan Bromberg on May 19, 2006, Niels Bohr Library and Archives, American Institute of Physics, College Park, MD, <http://www.aip.org/history/ohilist/30249.html>.
- ³⁸ Interview with Anne Reed and Linda Thomas, June 4, 2014.
- ³⁹ Peter G. Goetz et al., “Modulating Retro-reflector Lasercom Systems at the Naval Research Laboratory,” presented at the 2010 Military Communications Conference in San Jose, CA (Oct. 31–Nov. 3, 2010); G.C. Gilbreath, S.R. Bowman, W.S. Rabinovich, C.H. Merk, and H.E. Senasack, “Modulating Retroreflector Using Multiple Quantum Well Technology,” U.S. Patent No. 6,154,299, awarded November 2000. See more at <http://www.nrl.navy.mil/research/nrl-review/2003/space-research/creamer/#sthash.tk2yEg6p.dpuf>.
- ⁴⁰ Christopher I. Moore et al., “Overview of NRL’s Maritime Laser Communication Test Facility,” *Proc. of SPIE* 5892; Linda M. Wasiczko et al., “Characterization of the Marine Atmosphere for Free-Space Optical Communication,” *Proc. of SPIE* 6215, 621501 (2006).
- ⁴¹ Both images are from Moore et al., *Proc. of SPIE* 5892.
- ⁴² For a description of the interest in laser communications by the Office of Naval Research, see Linda M. Thomas, Christopher I. Moore, and William Rabinovich, “The ONR Enabling Capability on High Bandwidth Lasercom,” *Proc. of SPIE* 7685, Atmospheric Propagation VII, 76850I (May 04, 2010), doi:10.1117/12.850893.
- ⁴³ Nova-Sol company web page: <http://www.nova-sol.com/capabilities/optical-communications/dual-mode-optical-interrogator-dmoi>.
- ⁴⁴ Nova-Sol company web page.
- ⁴⁵ Interview with Anne Reed and Linda Thomas, June 4, 2014.
- ⁴⁶ Much of the material on Clementine is adapted somewhat from coverage of the program in my previous institutional history of NRL: Ivan Amato, *Pushing the Horizon: Seventy-Five Years of High Stakes Research and Technology at the Naval Research Laboratory* (Washington, DC: Naval Research Laboratory, 1998). See especially pp. 205–208.
- ⁴⁷ Material on Clementine came largely from two collections of papers—one technical and the other consisting of newspaper and magazine reports on the project—supplied to me by Paul Regeon. I also relied on a special issue of *Science* magazine (December 16, 1994; see note 52) in which much of the mission’s scientific results was reported. In June 1994, NRL also published a beautiful small volume, *A Clementine Collection* (see note 49), which includes useful information and anecdotes.
- ⁴⁸ BMDO, in turn, was renamed in 2002 as the Missile Defense Agency.
- ⁴⁹ *A Clementine Collection*, Naval Research Laboratory, NRL/PU/1230--94-261 June 1994 (reprinted March 1999), p. 6.

- ⁵⁰ <http://nssdc.gsfc.nasa.gov/nmc/masterCatalog.do?sc=1994-004A>.
- ⁵¹ Linda Greenway, "NRL develops spacecraft for cooperative deep space program," in *Labstracts*, Naval Research Laboratory, August 16, 1993.
- ⁵² Stewart Nozette et al., "The Clementine Mission to the Moon: Scientific Overview," *Science*, 266, no. 5192 (December 16, 1994), 1835–1839, doi: 10.1126/science.266.5192.1835.
- ⁵³ Nozette et al., *Science*.
- ⁵⁴ Linda Greenway, "Clementine—Not lost and gone forever," in *Labstracts*, Naval Research Laboratory, April 24, 1995.
- ⁵⁵ "Seventh Annual Best of What's New: The Year's 100 Greatest Achievements in Science and Technology," *Popular Science*, Dec. 1994, pp. 49 ff.; <http://www.nrl.navy.mil/clementine2/history.php>.
- ⁵⁶ *A Clementine Collection*, p. 22.
- ⁵⁷ William J. Clinton, "Report on Aeronautics and Space for Fiscal Year 1994," Congressional Record (Senate), p. S7388, May 24, 1995.
- ⁵⁸ Stewart Nozette, C.L. Lichtenberg, P. Spudis, R. Bonner, W. Ort, E. Malaret, M. Robinson, and E.M. Shoemaker, "The Clementine Bistatic Radar Experiment," *Science* 274, no. 5292 (November 29, 1996), 1495–1498.
- ⁵⁹ Paul Spudis, "Clementine—The Legacy, Twenty Years Later," AirSpaceMag.com, January 21, 2014, accessed April 2014 at <http://www.airspacemag.com/daily-planet/clementine-legacy-twenty-years-180949523/>.
- ⁶⁰ http://nssdc.gsfc.nasa.gov/planetary/ice/ice_moon.html.
- ⁶¹ Robert Mackay, "The Scientist Who Mistook Himself for a Spy," *New York Times*, October 21, 2009.
- ⁶² Associated Press, "Scientist Gets 13 Years in Spying Case," March 22, 2012.
- ⁶³ Aaron Chilbert, interview with author, February 21, 2012.
- ⁶⁴ Aaron Chilbert, interview with author, February 21, 2012.
- ⁶⁵ Art Collier, personal correspondence, April 22, 2012.
- ⁶⁶ Art Collier, personal correspondence, April 22, 2012.
- ⁶⁷ Art Collier, personal correspondence, April 22, 2012.
- ⁶⁸ Edward Senasack, interview with author, May 8, 2013.
- ⁶⁹ James Winkler, memoir, p. 35.
- ⁷⁰ John Schaub, interview with author, February 28, 2012.
- ⁷¹ <http://www.nro.gov/news/press/1996/1996-08.pdf>.
- ⁷² NRL Press Release, "Small Tether Satellite Deployed by NRL," June 20, 1996; <http://www.nrl.navy.mil/media/news-releases/1996/small-tether-satellite-deployed-by-nrl>.
- ⁷³ James Winkler, memoir, p. 91.
- ⁷⁴ <http://www.nrl.navy.mil/media/news-releases/1996/small-tether-satellite-deployed-by-nrl>.
- ⁷⁵ <http://www.nrl.navy.mil/media/news-releases/1996/small-tether-satellite-deployed-by-nrl>.
- ⁷⁶ <http://www.nrl.navy.mil/media/news-releases/1996/small-tether-satellite-deployed-by-nrl>.
- ⁷⁷ <http://www.nrl.navy.mil/media/news-releases/1996/small-tether-satellite-deployed-by-nrl>.
- ⁷⁸ Peter Wilhelm, interview with author, February 16, 2012.
- ⁷⁹ <http://www.nro.gov/news/press/1998/1998-09.pdf>.
- ⁸⁰ John Schaub, interview with author, February 28, 2012.
- ⁸¹ <http://web.archive.org/web/20070614150720/http://projects.nrl.navy.mil/atex/ATEX.html>.
- ⁸² Stephen S. Gates, Stephen M. Koss, and Michael F. Zedd, "Advanced Tether Experiment Deployment Failure," *Journal of Spacecraft and Rockets* 38, no. 1 (2001): 60–68, doi: 10.2514/2.3655.
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- ⁸⁴ Edward Senasack, interview with author, May 8, 2013.
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- ⁸⁶ Peter Wilhelm, interview with NRL Historian Leo Slater, August 7, 2009.

⁸⁷ K.M. St. Germain, G.A. Poe, and P.W. Gaiser, "Polarimetric emission model of the sea at microwave frequencies and comparison with measurements," *Progress in Electromagnetic Research* 37 (2002), 2–32.

⁸⁸ Peter Wilhelm, interview with Leo Slater, August 7, 2009.

⁸⁹ Peter Wilhelm, interview with Leo Slater, August 7, 2009.

⁹⁰ Wendy Lippincott, interview with author, May 1, 2012.

⁹¹ P.W. Gaiser et al., "The WindSat Spaceborne Polarimetric Microwave Radiometer: Sensor Description and Early Orbit Performance," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 42, no. 11, November 2004, available at http://www.nrl.navy.mil/WindSat/pdfs/TGRS04_Wind-Sat_Gaiser.pdf.

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⁹³ John Schaub, interview with author, February 28, 2012.

⁹⁴ John Schaub, interview with author, February 28, 2012.

⁹⁵ P.W. Gaiser, "WindSat — Remote Sensing of Ocean Surface Winds," *2004 NRL Review*, available at <http://www.nrl.navy.mil/research/nrl-review/2004/featured-research/gaiser/>.

⁹⁶ Daniel Parry, "NRL successfully completes first major development milestone on the NPOESS Microwave Imager/Sounder program," *Abstracts*, Naval Research Laboratory, September 14, 2009, p. 3.

⁹⁷ NRL News Release, "NRL's Microwave Imager/Sounder Passes Major Program Milestone," July 15, 2010, <http://www.nrl.navy.mil/media/news-releases/2010/nrls-microwave-imager-sounder-passes-major-program-milestone>.

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⁹⁹ John Schaub, interview with author, February 28, 2012.

¹⁰⁰ John Schaub, interview with author, February 28, 2012.

¹⁰¹ M.S. Johnson et al., "NRL Precision Orbital Transfer Vehicle," *2007 NRL Review*, Naval Research Laboratory, Washington DC, pp. 232–235, available at http://www.nrl.navy.mil/content_images/07Space_Johnson.pdf.

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¹⁰³ See, for example, R. Caron, "Mysterious microsattellites in GEO: is MiTeX a possible anti-satellite capability demonstration?" *The Space Review*, July 31, 2006, <http://www.thespacereview.com/article/670/1>.

¹⁰⁴ Johnson et al., "NRL Precision Orbital Transfer Vehicle."

¹⁰⁵ Johnson et al., "NRL Precision Orbital Transfer Vehicle."

¹⁰⁶ John Schaub, interview with author, February 28, 2012.

¹⁰⁷ Tom Betterton, interview with author, July 18, 2012.

OCEAN SURVEILLANCE, EVERYWHERE AND ALWAYS

Entirely classified until 2005 when the program's name and some of its story were declassified by the National Reconnaissance Office (NRO), Poppy evolved from its initial role in 1962 of finding, identifying, and characterizing fixed, strategic radar systems in the U.S.S.R. to also listening in on the electromagnetic signals emanating from mobile Soviet vessels at sea.¹ Beginning with its EOSAT program in the 1980s, the Soviet Union was doing the same thing.

As chronicled in Chapter Ten, the roots of Poppy's sea-vessel-directed intelligence roles date back to late 1967 when William N. Leonard (a World War II naval flying ace and commander of a carrier division who would retire in 1971 as a Rear Admiral), the Director of the Joint Chiefs of Staff's Office of Defense Research and Engineering, requested a study that included an assessment of the Poppy program's ability for "passive detection, classification, and localization of ships at sea."² This was a time when the Soviet Union was dramatically expanding its naval fleet. That request by Leonard now can be interpreted as prescient with respect to a far more ambitious intelligence framework, which by the early years of the new millennium would evolve into one of the most audacious and expansive ship monitoring capabilities ever developed. Often referred to as "maritime domain awareness," this system of systems co-evolved with the changing threats to the United States since the late 1960s.³

"We at NRL revolutionized—and I mean revolutionized—the nation's ability to attain maritime domain awareness," said Christopher Dwyer, who came to the lab in 1985 while still in college and worked his way up to become Superintendent of the Naval Center for Space Technology's (NCST) Space Systems Development Department (SSDD), now one of the two divisions of the NCST. He would serve also as acting director of NCST after the founding director, Pete Wilhelm, retired at the end of 2014. At NRL, SSDD, like the lab's other units, is known most often by its organizational code number, 8100 in SSDD's case. "The country went from tracking a couple hundred ships out on the ocean, to thousands and thousands. People said that was impossible," Dwyer noted with a touch of bravado. "Don't tell me anything is impossible."⁴ He should know: Dwyer served as the technical director for the Comprehensive Maritime Awareness Joint Capability Technology Demonstration (CMA JCTD),⁵ which in the first decade of the new millennium proved out many of the components of the overall system, as well as their integration.



Ocean Watcher. Christopher Dwyer, head of the Space Systems Development Department, is shown here with monitors displaying data about marine vessel traffic. (NRL photo 090707-N-4822B-004. jpg)

Dwyer points out that the system in place now was the result of a three-phase process beginning with a technology demonstration project—known as the Vessel Tracking Project (VTP)—that unfolded from 2004 to 2006. VTP demonstrated the empowering value of moving from what essentially was a manual process of gathering, correlating, and interpreting multiple sources and types of data about ships at sea to a more digitized and automated process. Following that, in the 2006 to 2009 time frame, was the buildup and execution of the CMA JCTD, which Dwyer helped to orchestrate and oversee. This went beyond vessel tracking, he explained, by adding the ability to discern which of the many ships out there are potential threats. “If you are monitoring thousands of ships, which ones do you worry about” is the key question, he said.

This is where a variety of ship data—among them ownership, flags, insurance status, crew information, and itinerary—come into the system to move it from one that merely tracks ships to one that can help determine which ships to worry about.⁶ Even as the CMA JCTD was going on, a third phase, known as MASTER—short for Maritime Automated Super Track Enhanced Reporting—also was under way. These two phases built on the lessons learned previously during the VTP to install, primarily for the U.S. Coast Guard, an operational “ocean awareness” system in the North Atlantic. And this, Dwyer noted, is just a step toward a fully global system, involving international partners, which would monitor and, and as Dwyer puts it, “threat-assess” thousands and thousands of ships everywhere and always.

The challenge of knowing what is going on with the world’s oceangoing vessels is harder than keeping track of aircraft. “In many cases, you can’t take off or land without asking permission,” Dwyer noted, pointing out that this entails that someone knows about your actions. “That is not the same on the world’s oceans, because maritime trade has been around as long as people have. It is not regulated to the extent that air travel and commerce is. It is very complex and not transparent at all. Ocean awareness is a tough problem to crack.”⁷

That it was a problem the Navy would have to crack was becoming apparent even in the late 1960s to forward-looking leaders like Rear Admiral Leonard who were

eyeing the Soviet Union's expansion of its naval capabilities and influence. "By the 1970s, the USSR's enormous investment in 'blue water' forces was evident in increasing Soviet deployments (in strength) in the Mediterranean, Arabian Sea, Indian Ocean and southwestern Pacific," according to a Navy-produced historical account of its own space activities.⁸ At the same time, ELINT tools, including Poppy satellites and associated intelligence-gathering field sites around the world, began reporting electromagnetic emissions at various global locations, reiterating that the Soviets were taking their naval assets further afield.⁹

The Mideast crisis in the fall of 1973, when Syria and Egypt launched a surprise attack on Israel and thereby increased the tensions between the already polarized U.S. and U.S.S.R., highlighted the growing potential of ocean-centric ELINT. During the crisis, the Soviets sent a veritable armada into Mediterranean waters. Until then, the Mediterranean had been known as "NATO's lake" to highlight the contrast between the heavy NATO and American military presence and the absence of Soviet naval power. But during what became known as the Yom Kippur War, the Soviets sent scores of vessels to the Mediterranean where they played a dangerous game of tag with floating and submerged American naval assets.¹⁰

Hundreds of miles above this watery theater were two sets of Poppy satellites—under the designators of Poppy 6 and 7—which were launched roughly four and two years earlier, respectively. The situation in the Mediterranean was ideal for moving forward on a proposed "hull-to-emitter-correlation" intelligence capability afforded by the satellites. Known as HULTEC, it was the ability to tie a specific radar to a specific ship, after detecting the electromagnetic emissions and accurately characterizing the specifics of those emissions, such as the frequencies, pulse durations, and repetition patterns. "You knew a particular radar was on a particular ship," Dwyer noted.¹¹ Poppy started out as a program to supersede the GRAB satellites, which in their early 1960s time frame were akin to the training-wheel phase of space-based ELINT. As discussed in previous chapters, the initial and primary role for both GRAB and Poppy was to identify and characterize major fixed radar systems such as the anti-ballistic missile (ABM) radar system surrounding Moscow and anti-aircraft radar systems installed throughout the Soviet heartland. But with each new and upgraded set of satellites in the seven Poppy launches between 1962 and 1971—along with upgrades in the ground stations and data analysis tools and techniques—it eventually became apparent to those in the national ELINT loop that the satellites couldn't help but pick up on ship-derived emissions as the payloads spent time over the oceans during their orbital trajectories. And it was clear too from analyses of those signals that some of them were coming from specific Soviet navy vessels.¹²

The last set of Poppy satellites, Poppy 7, was launched on December 14, 1971, from Vandenberg Air Force Base. As they had done for the lab's previous ELINT satellite launches, NRL's Reid Mayo and Vince Rose made sure all was well prior to takeoff.¹³ By then, Poppy 5, in orbit since May 1967, had entered its twilight phase.

Poppy 6 satellites, which had been designed to listen in on a wider frequency range than previous Poppy satellites, had assumed orbital positions on September 30, 1969. But NRO's partially redacted official history of the program, which was approved for release in 2012, reveals that command and telemetry subsystems in orbit failed to respond to interrogation by a mission ground station. In early 1970, one of the Poppy ground stations became "an emergency ward where [NRL's] Satellite Techniques Branch strove, pass after pass, to bring [REDACTED] back to life."¹⁴

During the Yom Kippur War, it would have been Poppy 7—whose primary ELINT targets were the strategic radar systems on Soviet territory—that conducted space-based ELINT collection on the Soviet ships and submarines in the Mediterranean and other blue water locations. The partial historical accounts of the program that NRO has released do not reveal if and how Poppy was used during that conflict, but one passage indicates that just months prior to the conflict, Poppy 7 was providing "good Ocean Surveillance coverage without detracting from the other missions of the system," referring to surveillance of Soviet land-based radar systems.¹⁵

The radar emissions from oceangoing vessels reached the early ELINT satellite systems at the speed of light. Even so, it could take days, weeks, months, and longer to work through the processing, analysis, packaging, and distribution of these raw interceptions of signals before they could be of value for strategic or tactical uses. These uses included planning of wartime bombing routes by the Strategic Air Command, teasing out the Soviets' electronic order of battle (EOB), and developing electronic countermeasures, including radar jammers or spoofers.

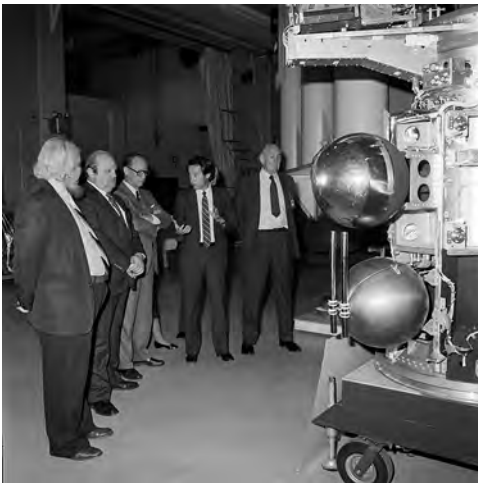
The fundamental challenge in deploying ELINT satellites to detect and track seagoing vessels for real-time, or at least near-real-time tactical use, resided in the speed at which the raw sensor-harvested data could be converted into information that fleet and ship commanders could act upon. For tactical operations, timeliness is everything. Contributors at NRL, the National Security Agency, the Naval Security Group, and elsewhere helped traverse major steps toward this required timeliness with developments in the tasking (of sensors to obtain relevant data), collection of data, and the processing, exploitation, and distribution of the data and information products derived from it. TCPED is the acronym that those deep in this loop use to refer to these five data-handling categories.¹⁶

In the same year as the Yom Kippur War, 1973, NRL executed organizational changes that would open pathways to technology developments required to leverage satellite systems for tactical uses, most notably ocean surveillance. In that year, for one, the Satellite Techniques Branch was renamed the Spacecraft Technology Center (Code 7040 within the Space Science and Technology Division, which was coded as 7000) under the leadership of Dr. Herbert Rabin, who at the end of the decade would become a Deputy Assistant Secretary of the Navy for Research, Applied and Space Technology.¹⁷ In-house champions at NRL of this emphasis on tactical applications included Fred Hellrich, who had helped secure state-of-the-art computer systems

and who handled multiple logistics issues during the GRAB and Poppy eras. He was assigned to head the Systems Development Section (7032). And Lee Hammarstrom was assigned to head the forward-looking Advanced Concepts Section (7033).¹⁸ In the ensuing years, he would develop a deep understanding and appreciation of the data handling, packaging, analysis, and distribution challenges it would take to move meaningful and actionable textual, pictorial, and other intelligence-laden media—much of it from classified sources, which added the challenge of having to keep its origins secret—from anywhere on the globe to anywhere else.¹⁹

“Ocean surveillance was an operational military system,” pointed out military space historian and writer Dr. Dwayne Day. “The data collected from an ocean surveillance system had to be immediately relayed to operators because the detected ships moved.” And the system had to have a global purview as the Soviet navy extended its operational capabilities. The Soviets showcased their growing naval power in a 1975 military exercise dubbed Okean 75, involving more than 200 naval vessels operating in the Pacific, Atlantic, and Indian oceans, as well as in the Mediterranean.²⁰

On April 30, 1976, an Atlas F rocket roared spaceward from a launch pad at Vandenberg Air Force Base in California and deposited into an initial orbit a trio of classified payloads that were hung onto the NRL-designed Multiple Satellite Dispenser, or MSD, which could gingerly maneuver several satellites into their own specific orbits.²¹ It was just one year before the official shutdown of NRL’s Poppy program.²²



Show and Tell. Pete Wilhelm, second from right, explains the technology and mission of the Multiple Satellite Dispenser (in the foreground) to representatives from the White House, with NRL colleagues on hand. (NRL photo P-1949(18).jpg)

Still untold publicly are descriptions of the countless engineering and technical innovations that it would take over the following years to put in place an ocean awareness system eventually capable of tracking and assessing in near real time a population of vessels numbering, as Dwyer has indicated, in the thousands and thousands. Daria Bielecki, a Ph.D. mathematician who arrived at NRL in 1988, was among the many partners who placed some of the foundation stones that would lead to this capability, in her case with her technical work and leadership in the Vessel Tracking Project.

From 1983 to 1988, before her years at NRL, Dr. Bielecki worked at the Naval Intelligence Support Center (NISC), then a part of the Ballistic Missile System Division of the Naval Weapons Technology Department (NISC now resides within the Office of Naval Intelligence). There, she analyzed the guidance, control, and accuracy of foreign ballistic missile systems, a signals intelligence (SIGINT) task. When she moved to NRL in 1988, she helped guide scientists and engineers in the then two-year-old NCST toward solutions to various mathematical and engineering issues associated with space system development. Key among these was oceanic vessel tracking.²³

A citation for the Navy Superior Civilian Service Award, which Bielecki won in 2009 for her many years of work in this exceedingly complex arena, provides a somewhat more technical window on the work she did. The award, the second highest a Navy civilian employee can receive, recognized Bielecki for her “development of the Vessel Tracking Project (VTP), which features a layered defense approach incorporating support from sensors, databases and information feeds ranging from national technical means [such as satellites] to open source information.”



Math Powerhouse. With particular strengths in mathematics and data fusion, Dr. Daria Bielecki played important roles in the Vessel Tracking Project, which fed into the larger Maritime Domain Awareness framework for identifying and tracking threats on the world's seas. (NRL photo BieleckiID.jpg)

As the Poppy program demonstrated, ELINT satellites could pick up relevant signals from Soviet naval vessels. However, these vessels were well-known threats. If the task was to become aware of and identify potential threats amongst all vessels on the world's oceans, then the overall system, in addition to being able to detect electromagnetic signals, needed to reveal who is on board the vessels, what is on board, who owns what is on board, who's buying what's on board, where the ships have been and where they are going, what nations they are flagged under, “and on and on,” said Dwyer. “Threat detection is almost infinitely more difficult” than merely tracking vessels, he added.²⁴

Bielecki's early work at NRL prepped her for the global-scale vessel tracking challenge that would become a pillar of a national maritime defense initiative, especially following the 9/11 attacks in 2001. She started out in the late 1980s in the Space Systems Technology Department (Code 8300) of the Naval Center for Space Technology.

There, she was tasked with looking into the intelligence-based question of how much information about, say, an ocean vessel and other kinds of vehicles one could glean from data stored on electronic identification chips, radio frequency identification tags, and other electronic data-containing technologies that were just coming into use. But when her growing expertise in that area landed her in what she described as a “customs activity” at Dulles Airport, near Washington, DC, she felt that her career was moving away from that of a technology developer to that of an intelligence officer.²⁵

It would have been a move that did not suit her. So she eagerly accepted an opportunity to apply her skills and knowledge to other efforts.²⁶ Her bosses were branch head George Price (son of Charlie Price who had learned during his Poppy days how to solve tough and geographically distributed logistics issues for global-scale projects) and Mike Regan, who, she recalls, “gave me the freedom to investigate any kind of sensor or intel source that I thought could be useful for this tracking work.”²⁷ Regan, who was not on NRL’s payroll, was a sponsor of NRL’s technology development work.

The particular vessel-tracking task she was asked to take on, Bielecki recalled, was akin to that of the cocktail party challenge in which one strives to hear the voices of a few friends among many strangers. “So you would have to use your other senses to find them,” she explained. “You might hear them talking, or listen to their particular laugh, or smell their perfume.” Pushing the art, science, and technology of ocean surveillance required a similar mind-set. “You had to use everything available to you to do ship tracking,” Bielecki explained.²⁸

“A lot of work you are doing when you come up with a ship track is to see if certain parameters go together,” such as ELINT and acoustic signals from sonobouys, she says. “You need to know about the source of the data and what to expect of the data. But then, when you are [trying to connect the dots] manually, you are looking to see if it all makes sense or not.”²⁹ The key to a practical system that could track thousands upon thousands of vessels was to automate the normally all-too-human task of making sense of the data. “That was the big breakthrough,” Bielecki noted in an interview. But it also had familiar roots at NRL. For example, the automation process involved, among many other details, teasing out signal characteristics of maritime navigation radars, including pulse repetition intervals (PRIs), which even the GRAB system relied on to do its job of monitoring Soviet land-based radar systems.³⁰

In the early 1990s, as a prelude to the technology tasks that a full ocean surveillance system would require, Bielecki and her colleagues in NCST and the lab’s Tactical Electronic Warfare Division (TEW) began working on a data component of that automation process by investigating the potential of an ELINT technology known as Specific Emitter Identification (SEI). The point of SEI is for sensors on ships, aircraft, and other mobile and fixed settings, to detect and analyze radar emissions from seagoing vessels and to integrate the traits of those emissions (frequency, PRI, etc.)

into specific electromagnetic portraits for each emitting radar. In contrast to the subsequently deployed public maritime Automatic Identification System (AIS)—which was not operational until the late 2000s and by which dedicated emitters on vessels deliberately (and by law) exchange information about a vessel's course, destination, and speed to other ships and appropriate maritime authorities³¹—SEI can help track and identify even vessels whose occupants are deliberately operating without having or activating an AIS emitter.

One of the earlier and more telling studies in this effort unfolded over a five-week period in 1991 at the United Kingdom Coast Guard site in Dover, England, the southeastern coastal town that is famous for its white cliffs made of the calcium carbonate remains of tiny sea creatures. It also is a so-called maritime choke point—the Strait of Dover is the narrowest segment of the English Channel and so it is like a cattle chute for boats, to mix metaphors. The UK Coast Guard photographed all ships that went through the Strait, which was one type of data that, with the addition of ELINT and input from a variety of sensors and databases, could help make vessel tracking work.

“We were trying to see how much info we could correlate from the pictures the UK Coast Guard had with the ESM [electronic surveillance measures] equipment tapping into SEI signals,” explained Bielecki, who led a VTP team of about 20 NRL colleagues, contractors, and academics from the Naval Postgraduate School in Monterey, California.³² Feeding into this operation were pictures from a company called PhotoFlight, which made a living by snapping photographs of ships in the Strait from the air and then selling the pictures to the ship owners and their passengers. Still at this time, nothing was automated or networked, so it took human eyes and brains to look for patterns and relationships in the different types of data. People were running up and down the stairs of the Coast Guard building in Dover trying to establish informative data correlations in real time as ships literally passed by in the Strait, Bielecki recalled.

“So we had pictures, we had the ELINT, we had the SEI from the ships, we had radar blobs,” Bielecki says. “We were trying to see how much info we could get and whether we could separate it into the uniqueness of vessels,” which is to say, into data portraits and signatures that identified specific ships. The plan was for each such portrait to go into a growing database (ultimately comprised of multitudes of databases) in order to make subsequent identifications and tracking tasks easier. A similar test was going on at another of the planet's primary shipping choke points, the Strait of Gibraltar between Spain and northern Africa. A sobering lesson of these exercises was that it simply was not possible for human beings, even teams of them, to manually fuse, integrate, process, and make sense of the different kinds of ship-related data in a timely and tactically useful way.

Bielecki was looking carefully at the system as a whole. If vessel tracking on the scale that the U.S. Navy, the Coast Guard, and other security organizations in the United States and elsewhere wanted was going to work, the process would have to be

automated as extensively and fully as possible. Toward that end, Bielecki said, she and her NRL colleagues initiated in 1994 a development project, the Chokepoint Monitoring System, at NRL's Chesapeake Bay Detachment (CBD).³³ A World War II-era research facility high up on the western shore of the Bay (replete now with a massive but defunct Cold War antenna structure for over-the-horizon aircraft surveillance), CBD provides, according to the lab, “facilities and support services for research in radar, electronic warfare, optical devices, materials, communications, and fire research.”³⁴ Here, in addition to everything Bielecki and collaborators tried in Dover, the team added data on each passing vessel acquired from an acoustic buoy and a high-frequency, surface-wave radar system. This was when some of the astonishing power of a mature vessel-tracking capability started to become apparent. Noted Bielecki, “you could sit in Building 59 [on NRL's main campus in Washington, DC] and you could see everything going on at CBD and you could see it through the Internet.”³⁵



Privileged Perch. NRL's Chesapeake Bay Detachment in Chesapeake Beach, Maryland, hosts a portfolio of research and development facilities and activities, including ones associated with tracking vessels and with the ocean surveillance system often referred to as maritime domain awareness. (NRL photo CBD. jpg)

To be sure, the technical, engineering, and information-related challenges that she took on in her various leadership roles over the years were huge by themselves. But developing the immensely capable tracking system that emerged from the Vessel Tracking Project, which was a foundational step toward global maritime domain awareness, also “required skill and sensitivity to overcome the natural cultural issues associated with coordinating the inputs from the large and disparate group of government agencies involved,” noted the lab's public information office in its announcement of Bielecki's Navy Superior Civilian Service Award. “Dr. Bielecki is cited as having ‘superb management skills and technical innovation that have contributed significantly to the security of the United States as well as the free world,’” the statement said.³⁶

Over the course of the next decade or so, into the first years of the new millennium, Bielecki headed up the “data fusion/correlation” task. The work centered on identifying the sensors (including ones on satellites, on and under the surface of the oceans, on planes, and on the ground by chokepoints), algorithms, automation

systems, and other small and large components that it would take to deploy a vast and complex system that is ever more able to monitor and track ever more vessels on the world's oceans.

In the course of all of these projects, Bielecki and various teams she has overseen participated in large demonstration exercises, among them *Crusade 2000*, a joint US-UK-led exercise held in March 2000 in Halifax, Nova Scotia. "The experiment included data from high-frequency surface wave radars, RADARSAT (a Canadian satellite), aircraft imaging sensors for ground truth/identification of national assets," among other components, Bielecki noted.³⁷ Beyond her involvement with the enormity and diversity of the technical issues that a global vessel-tracking capability entailed, Bielecki also spent much of her time conducting classified briefings to help sponsors communicate and negotiate with high-echelon decision makers and acquisition officials who were responsible for procuring and paying for all the system's pieces.³⁸

In 2003, when John Young, the Assistant Secretary of the Navy for Research, Development and Acquisition (ASN, RDA), called for a Maritime Domain Awareness architecture that would provide surveillance well beyond the Soviet and Chinese navies (which no longer were the most grave and most imminent threats to the U.S.), Bielecki was in a perfect position to begin what became a seminal contribution. "9/11 was what renewed interest in merchant vessels," thousands upon thousands of them, which suddenly were viewed by the defense and security communities with more urgency because they were likely means for terrorists to carry out attacks, Bielecki pointed out.³⁹

Her initial response to Young's request was to prepare a "white paper" on a much wider view of vessel tracking with help from NRL colleagues and partners at contractor firms. Because of her math expertise and penchant for quantification, Bielecki was able to provide Young with a cost figure, \$540 million, for a full-blown global-scale vessel tracking system. Young was impressed by the proposal, but he was unable to commit that much money, Bielecki said. His compromise was to implore Bielecki and her vessel tracking teams—which typically numbered in the dozen to 20 range, depending on the specific task—to do the best innovating they could with the \$30 million budget that he would be able to muster.

The approach Bielecki adopted was to look for the "low hanging fruit," which is to say, already available technologies that could work in the expanded vessel-tracking system Young and others wanted. Among this reachable technological fruit were hyperspectral imaging (beyond the visible range of the electromagnetic spectrum), high-frequency surface wave radar (designed for at-surface monitoring), acoustic sensors to listen in on ship sounds, and a host of other systems. One key task the team moved on was the Modular Sensor System (MSS), which Bielecki describes as "a remotely controllable automatic collection command center for multiple sensors, including Track While Scan (TWS) Radar, an advanced [Electronic Surveillance Measurement] system to provide Electronic Intelligence (ELINT) data, and a Precision Direction Finder (PDF)" to help locate the origins of radio frequency emissions. Explained Bielecki

in mild techspeak: “MSS forms a pool of sensors that can be configured to meet the individual needs for MDA at selected ports/sites with high automation and minimum manpower requirements.”⁴⁰

“And we had something called the Common Distributed Virtual Database for Information Extraction that brought all of this information together,” Bielecki continued. Those who work with this component of MDA actually refer to the entire acronym, CDVD/IE, like a series of words—Cee, Dee, Vee, Dee, Eye, Ee—and struggle to remember what the letters stand for. “The CDVD/IE semiautomatically identifies vessels via multisource data,” wrote the NCST team—including Mike Bell, Scott Elliott, Daniel Yang, and Piseyroth You—that had been developing the system. This provides the primary end user, the U.S. Coast Guard, “with maritime domain awareness of vessels operating in an area of responsibility (AOR) encompassing the Atlantic Ocean, north of the equator, and the Gulf of Mexico/Caribbean Sea.”⁴¹

The Coast Guard’s primary mission is maritime safety and crime fighting. This overlaps with, but is not the same as, the homeland security and defense missions of the Navy, Dwyer pointed out. In today’s defense-related context rife with terrorist worries, he added, MDA includes knowing such things as whether this or that vessel—among the many thousands of vessels in the system’s purview—has on board anyone on a terrorist watch list, or changed its identifying information mid-voyage.

A guiding principle for the overall MDA architecture has been to make as much of the system’s sensor data immediately available to many users of the system whenever a critical “point defense” situation might arise—such as a small, swift, and threatening boat approaching New York City. “For this reason, the entire operation of MSS is fully automated and can provide 24/7 situational awareness with no staff at all,” Bielecki wrote in 2008 in NRL’s annual book-length review of its researchers’ work. “For routine functional checks or an occasional reset of subsystems, the entire system can be maintained via a series of simple Web pages that not only provide situational awareness, but also allow the user to check on instrument and equipment status and health.”⁴²

One important demonstration along the way occurred in 2005 in collaboration with Canadian researchers working on homeland security, and participants and observers from the UK, Canada, Australia, and New Zealand. It was called the Maritime Seize and Interdiction Experiment, or MARSIE, and took place when Hurricane Katrina was wracking the Atlantic Ocean. “The idea was to track a merchant vessel going across the Atlantic carrying a homemade contraband package that the Canadians developed, that was then dropped in the fishing areas off of Newfoundland, picked up by a fishing vessel, then carried to the coastal waters and passed to a small boat or vessel,” Bielecki said.⁴³ Without going into details, Bielecki described the result as “successful” and a demonstration of “how you can bring technologies together” to construct new types of homeland security capabilities.⁴⁴

By 2006, the team began delivering to the primary end users—most notably at the Coast Guard’s Maritime Intelligence Fusion Center in Virginia Beach, Virginia—what eventually would amount to the most capable maritime domain awareness system on the planet: a system that can track hundreds of thousands of oceangoing vessels around the world in tactically realistic ways that can guide operations such as tracking, identification, and interdiction.

“Since the development of the VTP, the capability to collect, fuse, and correlate data continually and automatically from a variety of sensors that include electronic intelligence, imagery, Automatic Identification Systems [from ship emitters], and acoustics has drastically improved,” according to an NRL press release. In developing these capabilities, the statement said, Bielecki and her colleagues tapped into over 300 databases, among them the Coast Guard’s MAGNET [Maritime Global Awareness Network] database and the Office of Naval Intelligence’s Seawatch database.⁴⁵ These enhanced frameworks also accommodated additional data threads to link data about shipping companies, ships, banking, insurance, and other common attributes within worldwide databases, all in a quest to connect dots that might reveal previously hidden threats. These provide the means for converting a surveillance system that merely indicates that vessels of some kind are out there on the ocean to an “awareness system” that provides information relevant to assessing whether those vessels pose threats, Dwyer noted.⁴⁶

Bielecki and her many colleagues over the years also took the overall system way beyond ship tracking so that it could garner information automatically about the people and cargo on vessels, a capability showcased in the Comprehensive Maritime Awareness and MASTER Joint Capability Technology Demonstrations. According to an extensive tactics memo, written in heavy techspeak and issued by the Office of the Chief of Naval Operations, MASTER amounts to “a Web-based vessel-tracking tool that correlates tracks from sources across multiple security domains.”⁴⁷ NRL’s 2010 Fact Book adds that MASTER, whose present iteration is known as Sealink Advanced Analysis (S2A), “provides global, persistent, cooperative and non-cooperative maritime vessel tracking awareness and information that is valuable to intelligence analysts, joint warfighters, senior decision makers, and interagency offices within the SCI [sensitive compartmented information] community.”⁴⁸ That’s a matter-of-fact-way of saying something like “this system is one of the most far-reaching intelligence tools ever devised, built, and deployed.”

Dwyer outlined in the lab’s annual review in 2007 a few scenarios of how the evolving system could serve homeland security roles. “Once disparate sources of information are correlated and fused, the information is used to identify anomalies and threats,” Dwyer wrote. “Identification of anomalies might be as simple as automatically finding discrepancies between various data sources. For instance, as a ship approaches Long Beach, its AIS may indicate the ship’s name is Tokyo Maru. However, the automated tool searches databases and shows the Tokyo Maru was seen in Rot-

terdam one day earlier. The track would be flagged automatically. Another case could be a ship approaching Long Beach with an Advance Notice of Arrival indicating crew size of 34, when the last port of call in Singapore shows crew size of 30. An automated report would flag the ship for investigation.”⁴⁹

An initial and limited test of the evolving system unfolded in 2006 in an exercise centered at the Atlantic Area Coast Guard Maritime Intelligence Fusion Center in Virginia. But through the CMA and MASTER JCTDs (technology demonstration exercises), it was expanded in the following years by stakeholders—among them the Navy, Coast Guard, National Security Agency, Department of Defense, and Department of Homeland Security—to a global scale. Pivotal to the success of this effort was Dwyer, who, in the words of one observer, “skillfully coordinated a large number of national and international players to sell the CMA JCTD.”⁵⁰ JCTDs are massive, high-profile technology testing and proving exercises, rife with daunting logistical, administrative, communications, technical, and many other challenges. They are designed to preview the future of military technology and operations.

One enormous challenge in pulling off this large effort and in moving this system toward operational status, noted retired NCST director Pete Wilhelm, Dwyer’s boss until the end of 2014, “is protecting secure information and its sources while declassifying the appropriate information so it can be used by people who need it. Chris began by formulating a strategy to develop a ‘culture of sharing’ between international partners and the United States, and among U.S. agencies.”⁵¹ Another challenge, Dwyer added, had been to develop what amounts to a common language by which the human and machine elements of a comprehensive maritime awareness system can reliably communicate as they collectively produce, assess, and continually update the identification and perception of threats on the world’s oceans.

“The key to achieving that goal was to create a set of types and values that could be used to describe beliefs about maritime entities, relations, and events, as well as the evidence for those beliefs,” Dwyer and several collaborators outside of NRL wrote in the *2009 NRL Review*. What has been emerging from this work is a versatile net-friendly language schema, known as the Maritime Information Exchange Model (MIEM), that amounts to a universal language for describing, conveying, and communicating about the maritime threat environment in ways that are understandable and accessible to all of the people, computers, and other data-involved parts of the system. “Types” in this context refers to, for example, kinds of vessels, cargo, people, ports, and threats; “values” refers to, say, the size of a tanker, the normalcy or abnormalcy of a vessel track, or the degree of certainty about a potential threat.⁵² For the operational success of a system that monitors many thousands of ships around the world, “this was a big deal,” said Dwyer. “MIEM is a pivotal piece that allows this to work.”⁵³

There is more to come. The Vessel Tracking Project, which proved that intelligence systems as audacious as a CMA and MASTER might indeed be possible,

concentrated on “low hanging fruit,” Bielecki stressed, adding that there are “other sensors out there that will address different parts of the problem that will enhance capabilities.” The logical endpoint is clear enough: to have a relentless eye on the hundreds of thousands and even millions of vessels that comprise all maritime traffic on the world’s oceans and waterways and an ability to discern which of these vessels pose threats to the nation.

¹ Ronald Potts, *U.S. Navy/NRO Program C Electronic Intelligence Satellites (1957–1977)*; LEO Systems Program Office, National Reconnaissance Office, September 3, 1988; declassified with redactions and approved for release from NRO on June 13, 2012.

² Potts, *U.S. Navy/NRO Program C*, pp. 139–142.

³ Potts, pp. 139–142.

⁴ Chris Dwyer, interview with author, February 19, 2012.

⁵ <http://servicetoamericamedals.org/SAM/finalists09/nsm/dwyer.shtml>.

⁶ Chris Dwyer, interview with author, September 26, 2013.

⁷ Chris Dwyer, interview with author, February 19, 2012.

⁸ Applied Research Laboratory, The Pennsylvania State University (ed.), *From the Sea to the Stars: A Chronicle of the U.S. Navy’s Space and Space-related Activities, 1944–2009* (revised and updated edition, 2010), p. 74.

⁹ Potts, *U.S. Navy/NRO Program C*, Chapter 11; Dwayne Day, “Above the Clouds: the White Cloud Ocean Surveillance Satellites,” *The Space Review*, www.thespacereview.com/article/1351/1, April 13, 2009.

¹⁰ Dwayne Day, “Above the Clouds.”

¹¹ Chris Dwyer, interview with author, September 26, 2013.

¹² Potts, *U.S. Navy/NRO Program C*, Chapter 11. See pp. 223–224 for the launch history of the Poppy series.

¹³ Potts, *U.S. Navy/NRO Program C*, p. 212.

¹⁴ Potts, p. 181.

¹⁵ Potts, p. 219.

¹⁶ Chris Dwyer, interview with author, September 26, 2013.

¹⁷ Herbert Rabin bio, University of Maryland, <http://www.ece.umd.edu/faculty/rabin>.

¹⁸ A rough timeline for the Naval Center for Space Technology is available on NRL’s web site at <http://www.nrl.navy.mil/ssdd/ncst>.

¹⁹ Ivan Amato, *Pushing the Horizon: Seventy-Five Years of High Stakes Research and Technology at the Naval Research Laboratory* (Washington, DC: Naval Research Laboratory, 1998), pp. 334–336.

²⁰ Dwayne Day, “Above the Clouds.”

²¹ Official NRL manifest indicates the MSD was in operation for 41 days while its three payloads operated for 7 years and 9 months.

²² Robert A. McDonald and Sharon K. Moreno, *Raising the Periscope...GRAB and Poppy: America’s Early ELINT Satellites*, (Chantilly, VA: Center for the Study of National Reconnaissance, National Reconnaissance Office, September 2005).

²³ NRL Press Release, “Dr. Daria Bielecki Receives the Navy Superior Civilian Service Award,” April 6, 2009, <http://www.nrl.navy.mil/media/news-releases/2009/dr-daria-bielecki-receives-the-navy-superior-civilian-service-award>.

²⁴ Chris Dwyer, email correspondence, October 2, 2013.

²⁵ Daria Bielecki, interview with Art Collier, February 19, 2008.

²⁶ Daria Bielecki, interview with Art Collier, February 19, 2008; interview with author, April 12, 2012.

- ²⁷ Daria Bielecki, interview with Art Collier, February 19, 2008; interview with author, April 12, 2012.
- ²⁸ Daria Bielecki, interview with Art Collier, February 19, 2008; interview with author, April 12, 2012.
- ²⁹ Daria Bielecki, interview with Art Collier, February 19, 2008; interview with author, April 12, 2012.
- ³⁰ Daria Bielecki, interview with Art Collier, February 19, 2008; interview with author, April 12, 2012.
- ³¹ Daria Bielecki, “NRL Global Vessel Tracking Project (VTP),” *2008 NRL Review* (Washington, DC: Naval Research Laboratory), pp. 166–167.
- ³² Daria Bielecki, interview with Art Collier, February 19, 2008; Daria Bielecki, extended resume provided to author.
- ³³ Daria J. Bielecki, extended resume provided to author.
- ³⁴ <http://www.nrl.navy.mil/field-sites/chesapeake-bay-det>.
- ³⁵ Daria Bielecki, interview with Art Collier, February 19, 2008.
- ³⁶ Daria Bielecki, interview with Art Collier, February 19, 2008.
- ³⁷ Daria Bielecki, extended resume provided to author.
- ³⁸ Daria Bielecki, extended resume provided to author.
- ³⁹ Daria Bielecki, interview with Art Collier, February 19, 2008.
- ⁴⁰ Daria Bielecki, interview with Art Collier, February 19, 2008.
- ⁴¹ An article by an NRL team who developed CDVD/IE appeared in the *2005 NRL Review*: http://www.nrl.navy.mil/content_images/06Information_Bell.pdf.
- ⁴² Bielecki, “NRL Global Vessel Tracking Project (VTP),” 2008.
- ⁴³ Bielecki, “NRL Global Vessel Tracking Project (VTP),” 2008.
- ⁴⁴ Daria Bielecki, interview with Art Collier, 2009.
- ⁴⁵ “Dr. Daria Bielecki Receives the Navy Superior Civilian Service Award,” April 6, 2009.
- ⁴⁶ Chris Dwyer, interview with author, September 26, 2013.
- ⁴⁷ Office of the Chief of Naval Operations, Department of the Navy, Maritime Domain Awareness (Navy Warfare Development Command TACMEMO 3-32.1-10), Edition November 2010, pp. 2–13.
- ⁴⁸ *NRL Fact Book 2010* (Washington, DC: Nava Research Laboratory), caption on p. 108.
- ⁴⁹ Chris Dwyer, *2007 NRL Review*, pp. 165–167.
- ⁵⁰ Art Collier, personal communication.
- ⁵¹ Quoted at <http://servicetoamericamedals.org/SAM/finalists09/nsm/dwyer.shtml>.
- ⁵² Chris Dwyer, R. Hayes-Roth, D. Reading, and G. Small, “A Maritime Information Exchange Model (MEIM) for Sharing Actionable Intelligence,” *2009 NRL Review* (Washington, DC: Naval Research Laboratory).
- ⁵³ Chris Dwyer, interview with author, September 26, 2013.

C4ISR: A QUEST FOR OMNISCIENCE

With projects like LACE and Clementine for missile defense; the never-flown Interim Control Module for the International Space Station; the Upper Stage for classified payloads; the Windsat and its indefinitely shelved follow-on Microwave Imager Sounder for fine-grained monitoring of meteorological and ocean conditions; the space tether payloads TiPS and the ill-fated ATE_x; and the late 2011 milestone launch of its 100th satellite, TacSat-4 (see Chapter Sixteen), NCST surely remained in the satellite-building game from the 1980s into the new millennium. That, even as its primary initial sponsor in the 1960s, NRO, switched in the 1970s and 1980s to a policy of acquiring its systems from industry partners rather than funding organizations like NCST to build them. A large portion of NCST's work always would remain in space hardware, but more on the component and systems scale, rather the full-satellite scale. A portion of NCST's work also would always remain classified. But a sea change for NRO meant a sea change for NCST.

For NCST as an institution, the strategic shift resided in reconsidering the payloads it had built, or helped design, for industry partners, as "orbiting peripherals" within a much larger technological context of C4ISR. Spelled out, C4ISR in long form comes to "Command, Control, Computers, Communications, Intelligence, Surveillance, and Reconnaissance." Think of it as an evolutionary and ever-expanding project to build a globally distributed megasystem of sensors, electronic boxes, data-processing modules, communications devices, and a long list of other gadgets and components that sum into a means for providing real-time, all-the-time, anywhere and everywhere awareness about whatever military, terrorist, or other security threat might be lurking out there. It's a big enough project to occupy hundreds of NCST personnel and their contract partners. It is that audacious, at least in theory.

"We started out as a space science group back in the 1950s. Then we evolved into a space technology program, one program in particular," observed Robert "Ike" Eisenhower in an interview. Already working at NRL in 1962 as the Poppy satellite ELINT program was getting under way, Eisenhower had taken the helm of NCST's Code 8100, the Space Systems Development Department (SSDD), when it formed in 1986 and held that position until his retirement in 2008. The one particular program Eisenhower is referring to was the one that began with the GRAB and Poppy satellites under NRO's sponsorship. The program was entirely classified until 1998 and 2005 when portions of its earliest history with the GRAB and Poppy projects, respectively, began to become "tellable." "But then we evolved even further into a C4ISR program."¹



Robert Eisenhauer, at NRL since the 1960s, took over as head of Code 8100, the Space Systems Development Department, when it was formed in 1986 along with the Naval Center for Space Technology (Code 8000). He is shown here at a clean desk in 1989. (NRL photo P-2792(11).jpg)

In time, the satellites became merely the highest-altitude components of a much larger intelligence technology ecosystem that processed, packaged, analyzed, and otherwise recast the raw intelligence data from satellites and other sensor-bearing platforms into information products that had operational and tactical value for an extensive range of users. These users resided primarily in the arenas of national defense, intelligence, security, and eventually even law enforcement and emergency response communities. The term “orbiting peripheral,” Eisenhauer recalled, started out as a good-hearted joke from a contractor that the NRL satellite team was working with closely in developing processing software for ground stations, but it became an apropos term for much of NCST’s *raison d’être*.²

“If it falls under that umbrella, C4ISR, chances are we are doing something in there,” said Eisenhauer in an interview. “If we are not collecting and processing the data, we are taking that data and figuring out how to distribute it worldwide or how to combine it along with other types of data, and how to turn out products, such as targeting information, and then broadcasting that back out to receiving terminals so the actual guy in the field has the target data now.”³

In a sense, the rebalancing of NCST’s portfolio with C4ISR technologies since the 1980s has reconnected the Center with NRL’s early history in pushing the boundaries of radio communications, a tactics-minded quest. The difference is that the communications and intelligence landscapes have diversified and expanded to wondrous and daunting scales. Despite widespread interest to improve and expand tactical use of national intelligence capabilities, it took some time for Eisenhauer and his NCST colleagues to develop the sponsor relationships and internal cultural mindset they needed to move forward on these ideas.

“Our primary customer always has been the military operational forces, tactical support, as opposed to what the rest of the NRO does, which is more strategic than tactical,” noted Art Collier of the former Special Projects Office (also designated as SPAWAR 004-5). Later, he became a consultant to NCST.⁴

Even in the 1970s, noted Collier, the lab’s satellite technology contingent began to realize that its primary user base—the U.S. government in general and the Navy in particular—was unable to fully exploit the available intelligence. “They did not have the automated systems that would enable them to process it quickly enough,” said Collier, referring primarily to the data acquired from intelligence satellites—“the national technical means”—that NCST built or helped design. “So we said ‘hey, we need to get in there and help them use the data that we were giving them’ and that spawned the impetus within the program to develop the tactical side and figure out how to process the data and display it rapidly and effectively.”⁵

This insight meshed with a push by the U.S. Army in the early 1970s to exploit, in the words of an administrative history of the Navy’s space activities, “national satellite-based reconnaissance systems in support of its tactical forces on the ground.”⁶ This led to Army efforts to develop concepts and hardware that would put intelligence data from national systems into the hands of corps-level users. It caught the fancy of Congress, which in 1977 strongly encouraged all of the military services to move in a similar direction. The Navy’s first follow-through on this request was to establish the Navy Tactical Exploitation of National Capabilities (TENCAP) Office as a branch within the Office of the Director of Navy Command and Control.⁷

In some ways, there was nothing new here. The naval intelligence community had long embraced the practice of supporting the operational fleet with the information it had access to from national reconnaissance systems, including Poppy ELINT satellites. But the Congressional push in this same direction, and the official establishment of a Navy TENCAP effort, “became a significant factor in improving the usefulness of space-based surveillance and reconnaissance to the fleet,” according to the administrative history of the Navy’s space efforts.⁸

In the 1980s, the Navy TENCAP Office orchestrated research and development projects that earned a reputation throughout the Department of Defense for getting things done faster and leading to results at a fraction of the cost, compared to other military services and intelligence organizations. Some of these other organizations were eager enough to partner with the Navy researchers, many of them within NCST, that they kicked in funds, leading to a growth in joint agency TENCAP R&D projects. Participation of specialized contractor firms grew dramatically, amounting to up to half of the technical personnel for TENCAP programs.⁹

One of the first at NRL to realize that the seemingly denigrating phrase “orbiting peripheral” actually amounted to a signpost pointing toward a potentially sustainable and fund-attracting trajectory for NCST was Eisenhower. Soft-spoken, yet confident and proud of having been a leader in his country’s space-technology community

for decades, Eisenhower, who died in 2016, was not one for denial that the context was changing and that NCST would either adapt or fade away. He had been in charge of much of the electronics work that NRL's satellite technologists had developed and built over the years and he could see that much of what it would take to realize the TENCAP ideal would be anchored in electronic boxes that could do wonders with electromagnetic signals—including a veritable tower of Babel of radio formats known as waveforms—and data.

“Eisenhower saw that our relationship with our traditional sponsors was changing,” observed SSDD superintendent Chris Dwyer. “And we needed to go figure out how to stay alive by redefining our business model and doing other things,” that is, other than building classified satellites.¹⁰ Eisenhower could see the coming emphasis on tactical systems even in the 1970s, noted Dwyer, an electrical engineer who began working for Eisenhower in the summer of 1982 as a student contractor. Eisenhower hired him in 1985 and by 2004 Dwyer had worked his way up to run NRL's branch coded as 8140, and known more verbosely as Command, Control, Communications, Computers, and Intelligence (C4I). In 2009, he succeeded Eisenhower as superintendent of SSDD (Code 8100).

“The requirements of the systems were constantly changing and so the technology was constantly changing too,” Eisenhower explained, referring to the ELINT and other intelligence, surveillance, and reconnaissance systems that NRO was acquiring and operating. The NRO always had a national-scale purview, and early on, NRL's satellite work with the NRO reflected that bias. But for Eisenhower, the strategic question that NCST had to fully take on if it were to stay in business even as the NRO shifted the satellite-building business to industry was this: “What good is intelligence if you can't get it to the guy who needs it on the tactical leading edge?”

It was one of the questions driving the Navy's TENCAP efforts. It was also a question whose roots for NRL and NCST extend even to the 1960s when those within the Poppy infrastructure were seeing evidence that the nation's SIGINT (signals intelligence, which includes ELINT and COMINT, that is, electronic intelligence and communications intelligence) satellites could play an important and unprecedented tactical role for the U.S. Navy by identifying and even tracking Soviet military vessels at sea.¹¹ If the satellites were the orbiting peripherals, then the rest of the system would have to quickly get the data from these space-based sensors—and other sensor assets—to those military personnel at sea, and on the ground and in the air, who could use the data to avoid, track, or target the enemy. A buzz phrase Eisenhower likes to utter to encapsulate this satellite-to-warfighter pathway is “sensor to shooter.”¹²

For NRL's ELINT satellite systems, “we knew what the data product was that was coming out of it,” said Eisenhower. This led to a natural diversification of NCST's business to develop technologies in the overall system that moved data from the periphery (from the sensor) to the user (to the shooter, as it were).

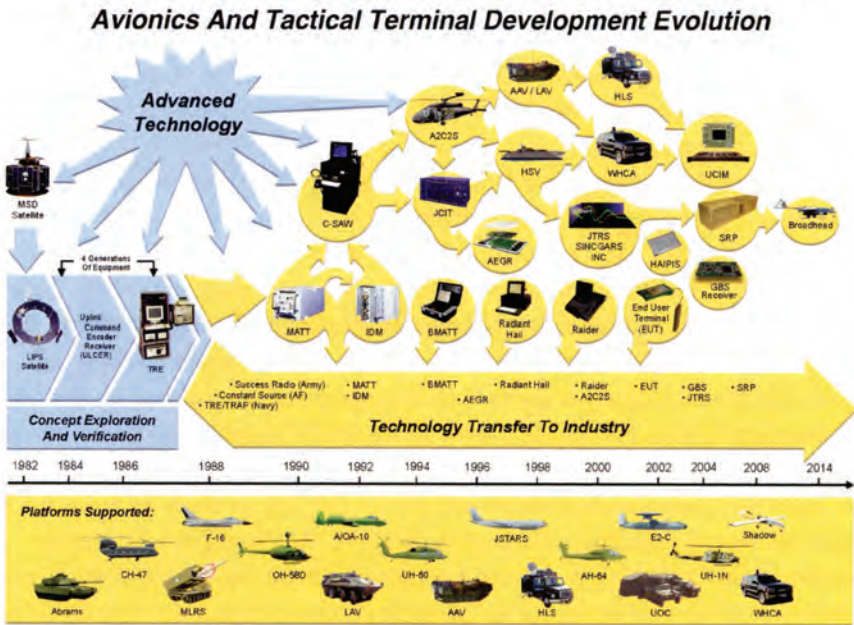
Distributing and delivering the tactical data to the user amounted to a technical challenge that, in Eisenhower's words, took NCST "into programs ongoing today that you never would have thought it would have been tied to."¹³ There is an irony here for the Naval Center for Space Technology in that in order for the organization to remain a player in the Space Age it helped establish in the 1950s, it would have to shift a sizeable portion of its work back down to Earth. Much of NCST's research, development, and engineering portfolio would have to become devoted to ground-based data and signals processing, and communications systems. On top of that, as NCST engineers were innovating the hardware, algorithms, software, and systems to do just that beginning in the early 1980s, the information landscape was undergoing its own dramatic transformation driven by the advent of the World Wide Web, Internet, and net-centric everything.

"It was all about taking our bright, smart engineers, who know the sensors and what kind of data come from them, and figuring out ways of getting that data into tactical users' hands," said Eisenhower.¹⁴ The first deliverables for the end user, in the early 1980s, would become known as Tactical Receive Equipment (TRE). These units would enable existing radio equipment on floating naval vessels to receive data broadcast by the satellites, but also to filter the data so that it would reveal to end users only specified signals of interest within geographical areas of interest. In its first incarnation, "it was a modem to go into existing radios," according to Robert Burdett, who was among the small team of engineers in Eisenhower's department in Building 59 where they designed and built the first units.¹⁵ The TRE, in effect, turned a regular radio receiver into one that could access a variety of ELINT products, including satellite-derived ones. In time, Eisenhower pointed out, the equipment would diversify and become ever more sophisticated. "It would get down to the point where it could fit into small handheld devices that would tailor the information for a mission when a soldier is in the field," he said.

"We took what we knew about space, and how to design things that went into space—that had to be small, lightweight, low power, modular—and started applying that knowledge and know-how and engineering skill, along with what we knew about sensors and receivers, to other stuff," added Dwyer. "This is C4I on the ground, air, and sea," he said, acknowledging the apparent historical twist in a space-based organization like NCST becoming heavily invested in more surface-based technologies.¹⁶ But that is how it always was and had to be. After all, satellites are connected to a much larger system by which the satellite data can provide both long-term strategic value and up-to-the-second battlefield tactical value.

"At first we were using management reserve dollars" to build prototype devices that would demonstrate how the Navy could extract more tactical value from intelligence data, noted Collier. When the NCST team started to roll out technologies that could do just that in practical ways, other military services wanted in and began to fund NCST to carry out additional prototyping work.

With each passing year over the past few decades, there have been ever more computers, databases, optical fiber trunks and satellite links, communications systems, sensors and surveillance systems, transmitters and receivers, indeed more of everything when it comes to acquiring, processing, packaging, transporting, and using data. The civilian version of this is sophisticated all right, but it is the digitized battlefield that pushes toward the impossible and is sometimes reality-checked by that boundary.



C4ISR and More. This chart of C4ISR technology, from a long-time industry partner with NRL, Assurance Technology Corporation, illustrates the evolution and proliferation of electronic sensing and communications "black boxes" for deployment on the ground, sea, air, and space.

Many NRL researchers have their imprints on the myriad pieces comprising C4ISR, most of them known by acronyms (the long forms of which even their designers and champions sometimes fail to remember). TRE: Tactical Receive Equipment. MATT: Multi-Mission Advanced Tactical Terminal. Add a B, to get BMATT, for Briefcase Multi-Mission Advanced Tactical Terminal. JTT: Joint Tactical Terminal, and its briefcase model, the BJTT. JTRS: Joint Tactical Radio System. SDR: Software Definable Radio; and SDRP: Software Definable Radio Payload. IDM: Improved Data Modem. A2C2S: Army Airspace Command and Control System. UCIM: Universal Communication Interface Module. TacSat: Tactical Satellite. There are more, many more.

Focusing on the list all at once is a sure way to lose the C4ISR forest for the trees or even the leaves, especially if one drills into the specific circuitry, radio frequency engineering, algorithmic, and other technical advances at the heart of each of these



C4ISR on Parade. NCST engineers and their partners have diversified command, control, computers, communications, and intelligence (C4I) technologies into systems for a range of end users. In the aftermath of the 9/11 attacks, NCST and its partners mixed and matched technologies they had developed in the past to make them applicable in more of the threat situations of concern to changing national and homeland defense communities.

acronyms. For most of these and other related components and systems, the hold-in-your-hand, or rack-in-a-stack, object associated with them is one or a suite of electronics-filled boxes with sizes ranging from cracker boxes to kitchen appliances. “The IDM and other NCST tactical efforts came from using the dense satellite packaging techniques to put all of the functions required to handle the digitized data in a modest-sized package,” summed Lee Hammarstrom, an electrical engineer who had been a behind-the-scenes driving force in many national defense technologies and whose ties to NRL date back to the early 1960s.¹⁷ NRL’s space technologists always have been good at designing and building such boxes. Dust-covered prototypes, testing and evaluation models, some of them decades old, populate window sills, the tops of file cabinets, and other nooks and crannies of NCST’s work and laboratory spaces.

One of the primary starting points that led to NCST’s sensor-to-shooter technology portfolio—and from there to an extended portfolio of C4ISR technologies that could be of use also to nonmilitary markets including law enforcement, emergency response organizations, and even the White House Communications Agency (see Chapter Sixteen)—unfolded beginning in 1980. That is when Pete Wilhelm, then director of the pre-NCST Spacecraft Technology Center, initiated the effort that transformed what had been an expendable component of the Multiple Satellite Dispenser (MSD), which he and his NRL team had been building for years, into an on-orbit tactical communications transponder.

The 6-foot-diameter, annular-shaped “plume shield” previously had only performed the transient job of protecting the satellite payloads—particularly their delicate optical elements, solar cells, and sensors—from exhaust plume and particles as the payloads were maneuvered from a primary orbit to their final operating orbits and then separated from the MSD. Normally, once its job was done, the shield would become yet another piece of space junk. But during a meeting with partners in some of NRL’s space technology projects, Wilhelm came up with the idea that a quick and inexpensive way to test out whether it would be possible to deliver tactically useful intelligence data to the floating fleet would be to modify the plume shield so that after its normal role, it could serve a second and long-term lifetime as a convenient and already orbiting technology test bed.¹⁸

At a meeting back at NRL where Wilhelm first floated the idea, a participant asked him what the satellite would be called, recounted James Winkler, a then nearly 20-year space engineering veteran with NRL. When Wilhelm replied, “LIPS,” Winkler continued, “there were a few snickers from the group but Pete explained that this acronym stood for Living Plume Shield.” There was another less-fun surprise at the meeting. “We had just six months to design, build, test, and deliver the satellite to support a December launch,” said Winkler, who would get the job of spacecraft manager.¹⁹

“The initial reason for LIPS was to prove the feasibility of using a low Earth orbiting [LEO] satellite to broadcast into the polar regions for tactical communications in addition to the [much higher flying] geosynchronous satellites,” Eisenhower noted. “We had to make sure we could receive data from the rapidly moving satellite at sea aboard maneuvering vessels.”²⁰ A longer-range view was to see if a repurposed and properly equipped plume shield could become an orbiting relay—a so-called bent pipe—for relaying streams of digitized data originating from a variety of sources so that the data could become tactically available and swiftly accessible to a multitude of military end users.

The basic several-minute sequence went something like this: First, satellites, aircraft, and ground sensors would send data about intercepted signals to their usual “ground segment”—the ground stations—where the raw data would be automatically processed into useful information for characterizing adversaries’ (mostly the Soviets until the 1990 time frame) radar emissions. That done, the now tactically parsed data would get reformatted, encrypted, and otherwise prepared for transmission to floating naval vessels. A sophisticated electronic box at the ground station, dubbed Uplink Command Encoder Receiver, with the comedic acronym ULCER, carried out this reformatting task. This unit would then send the tactical-information-bearing signal to an antenna in the ground station network that was placed in such a way that it could beam the signal stream to the orbiting bent-pipes, that is, low Earth orbit and geosynchronous communications satellites with lines of sight to all recipient naval vessels within their fields of view. The transponder in the system is referred to as a

“bent pipe” because it does no further processing of the signal; it receives a signal from one location and relays it downward in all directions (omnidirectionally), thereby diverting a linear transmission into a horizon-to-horizon broadcast.²¹

In a way, the LIPS mission was a prescient precursor to a big conceptual push in the satellite community, beginning in the early 1990s, to build “smaller, cheaper, faster, and better” satellites.²² Lightsats, cheapsats, smallsats, microsats would all become part of the space technology lexicon in this regard.

In preemptive accordance with that future small-is-better approach, it took less than six months from the conception of LIPS, and only \$2 million (instead of significantly more for a stand-alone space experiment requiring its own newly designed satellite), for a team of about three dozen NRL space technology engineers to modify a plume shield into a powerful, on-orbit communications relay. The first LIPS to make it to orbit, a redesigned version of the original one, was 6 feet in diameter, 4 inches high, and weighed 130 pounds.²³

“Part of the reason this was even possible,” observed Winkler, “was due to the innovative fabrication technique for the structure. It was to be made almost entirely of aluminum sheet metal. The exception was the center cylinder that was manufactured by rolling an aluminum C-beam into a cylinder. The highly skilled machinist who accomplished this was Vic Callahan, assisted by Joe Collins and George Gregory,” who were among the hands-on experts that converted ideas about space technology at NRL into launchable hardware. Added Winkler, “The other innovation was to build the various parts from sketches and then develop the engineering drawings from the parts,” an approach from the past that was essentially backwards from the usual and more time-consuming approach of developing the engineering drawings first.²⁴

In a memoir of his years at NRL, Winkler provided a snapshot of the kind of teamwork it took to build space-worthy high technology, such as the LIPS satellites, at a breakneck speed. (1) A thermal design crew, headed by Jack Hunter and Charlie Buhler, designed individual enclosures—each with multiple layers of thermal blankets and their own strip heater and thermostat—for each black box on LIPS. (2) Battery experts Fred Betz, Wilbert Barnes, and Skip Shepherd built and tested, wrote Winkler, a compact nickel-cadmium battery pack and lightweight solar panels. (3) Bill Collins, the go-to guy for gravity-gradient-based attitude controls, delivered a reliable and lightweight boom and damper system. (4) Bob Burdett and Mark Johnson managed to combine a power-stingy central processor, an analog-to-digital converter, and other components into a lightweight telemetry system. (5) The RF system was Len Hearton’s work, with help from Leo Ferrari and Joe Mattaino and an ultra-high-frequency (UHF) transponder featuring a deployed boom antenna designed, built, and tested by Fred Domer. (6) Under the direction of Robert Palma, a small team designed the electrical power system and in a second task, Palma, according to Winkler, “designed the Ordnance Control System which fired the pyrotechnic devices that released the RF boom and the Gravity Gradient boom and damper.”²⁵

There was more to it than that. The six-month schedule would have been impossible to meet, Winkler noted, were it not for the variety of on-hand technical support groups, among them ones for electrical and mechanical fabrication, environmental testing, launch vehicle integration, orbital tracking and operation, and the lab's support divisions, including the Supply Division, the Engineering Services Division, and the Travel Office.²⁶ This ability to mix and match a huge diversity of skill sets always has been one of NRL's greatest strengths.²⁷

All of this work and all of these people worked together to build the first Living Plume Shield, or LIPS 1, and have it ready for launch aboard an Atlas F rocket at Vandenberg Air Force Base on December 8, 1980. As a tough reminder of how risky any rocket-based technology was, this first LIPS assembly never made it into orbit: the Atlas F failed soon after it lifted off.

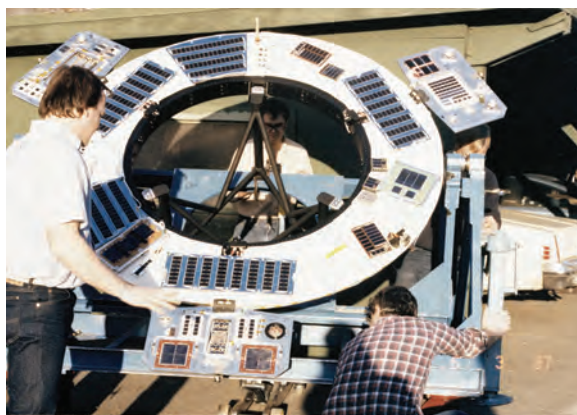
The outcome was better the next time around, which was just over two years later. LIPS 2 launched successfully on February 9, 1983, atop an Atlas H rocket. It carried a single-channel, ultra-high-frequency transponder—the bent pipe. And its performance demonstrated that it should be possible to relay space-gathered intelligence in tactically valuable and timely ways to a diversity of potential users, ranging from fleet commanders at sea perhaps to individual warfighters equipped with appropriate receiving radios for the tactical data.

The next in the LIPS series, LIPS 3, was launched successfully on May 15, 1987. But Winkler and a team, including Pete Wilhelm, who were at the ground station at



LIPS Service. The first successfully launched satellite in the Living Plume Shield series, LIPS 2, went into space in early 1983. It was developed by modifying a launch vehicle's protective shield that is usually jettisoned in space. The LIPS 2 satellite was used as a demonstration program to prove the capability of the direct downlink of tactical data from a low Earth orbiting spacecraft. The LIPS satellites were designed, built, and tested by the Spacecraft Engineering Department at NRL's Payload Processing Facility. (NRL photo 79878(41).jpg)

Vandenberg AFB, soon had reason to worry. The spacecraft was designed, built, tested, and prepared for launch in under nine months.²⁸ The project had little to do with the tactical use of intelligence data, but furthered the frugality of the LIPS concept for which Wilhelm, Eisenhower, and others saw a lot of promise. The brainchild of NCST physicist James Severns, and once again under the project leadership of Winkler, LIPS 3 served primarily as a platform for doing head-to-head tests of more than 140 experimental solar cell and power devices designed by 18 different research laboratories and aerospace firms.²⁹ To accommodate cell designs involving optically focusing sunlight into tighter areas, the roughly 30-person LIPS 3 team had to include precision attitude control on the 130-pound LIPS 3 platform to maintain an advantageous orientation with respect to the sun.³⁰ As was generally the case, this mission included at least a few innovations. “One of the unique features of this satellite was a passive Attitude Control System (ACS), which employed magnetic coils to maintain the orientation of the satellite, obviating the need for reactive jets and mission-limiting fuel,” Winkler noted.³¹



LIPS 3. Living Plume Shield 3, and its payload of multiple test panels of solar cell materials and technologies, is readied for launch. Launched on May 15, 1987, LIPS 3 provided a test bed for new space power sources. It provided data obtained from more than 140 new solar-cell experiments configured on a primary spacecraft's plume shield, which in the past would have become nothing but a piece of space debris. Like its predecessors, LIPS 3 was designed and built in less than a year. Engineer Robert Towsley is standing on the left. (NRL photo 99-130.jpg)

As the spacecraft made its very first pass over the ground station, Winkler was preparing to send command signals to deploy the solar cell panels and to confirm that the attitude and the spin rate, key for stabilizing the satellite, were in good stead. “If we did not accomplish this on the first pass, it was possible that the satellite-generated power would be insufficient and we might lose everything,” stated Winkler, who was in charge of the pass procedure at the Blossom Point ground station in Maryland. The telemetry data indicated that the attitude and spin rate were completely outside of the specifications. “Nothing looked like what we expected.”³²

The pass would only last 12 minutes and Wilhelm made the call to send the command to deploy the solar panels regardless of the telemetry data. That's when the whole ground station went down. Frantic action by the crew got the ground station up again in time to send the deploy command before the pass was over. But that didn't work either. With time waning, Winkler ordered the use of a back-up command. The panels finally deployed.

That was a good result, but there still were problems. Rather than spinning smoothly, the spacecraft was wobbling like a tottering spinning top. One of the LIPS team members, Robert Towsley, identified a fix: by firing a pulse from an attitude-controlling jet nozzle at a specific point in the rotation, the wobble could be minimized to an acceptable degree. "We tried it," recalled Winkler. "It worked perfectly! Although used by others in the space business, NRL dubbed it the "Towsley maneuver."³³ LIPS 3 operated in its orbital perch for the next six years.

As one team of NRL space technology engineers worked on the transmission side (the orbiting LIPS side) of making tactical data available to operational forces at a more useful classification level, another NRL space technology contingent was working on the receiving side of the system on the ground. That meant designing radios for receiving the tactical transmissions. These boxes would become known as TREs, short for Tactical Receive Equipment. These would become the starting point for an astounding evolution of CAISR technologies and capabilities, most of them in the form of unpretty electronics-loaded boxes, countless lines of computer code, intangible cryptographic and broadcast protocols, and an overall system design without which any complex technology frameworks like this would amount to not much at all.

Among the components in a TRE unit—the portal by which warfighters would gain access to the massive system—would be a UHF satellite communication receiver, cryptographic modules, and a message processor. Although former NCST electronic engineer Chris Herndon and his colleagues designed and built the prototypes, the San Diego-based Naval Ocean Systems Center (NOSC)—a laboratory then subordinate to the Naval Electronics Systems Command (NAVALEX), which would morph into the Space and Naval Warfare Systems Command (SPAWAR)—would orchestrate the manufacture and certification of production TRE models that made it into the field in the 1990s.³⁴

It began, Herndon recalled, with a series of radios, most notably ones dubbed the MDR 610 and MDR 1210,³⁵ which he and his fellow electronic engineers built to test out the system. "Before you can reliably think that you could deliver data to the warfighter, you have to do all sorts of series of tests," said Herndon, who left the lab in 2005. "Most of the space-based platforms were low Earth orbiting satellites. These are not like the geosynchronous birds that stay above the same known spot of the Earth all day and night. With a LEO satellite, you have to know the ephemeris [orbital trajectory] to see where it is going to be, so you can have the radio's antenna pointed for what is called AOS—acquisition of signal—and so it will track the satellite across its orbit

plane. Depending on where it is on the horizon, you may get a signal from the satellite for 7 or 8 or 12 minutes, all depending on the type of orbit it is in and where it is in reference to you.”³⁶ The first TREs, Art Collier noted, were designed to interface to existing shipboard UHF antennas, which could receive signals from all directions and so did not have to track the moving satellites.³⁷

In addition to the challenge of overhead passes that last only minutes, the satellites’ signals “have to be robust and work even in the presence of powerful search radars” (and other potential sources of electromagnetic interference including deliberate jamming systems), Herndon pointed out in an interview. “All of those kinds of questions and tests are basically aimed at measuring the quality of the link.”³⁸ What’s more, the satellites’ signals needed to include built-in means of revealing errors in the data streams, and the TREs needed to be able to operate in the electromagnetically busy shipboard environment.³⁹ The NRL team worked closely with Mnemonics, a Melbourne, Florida-based contractor, to procure these prototype radios, which became the basis of production TREs.

“As the on-orbit systems were checked out and data had been validated and we were pretty confident of the reliability, accuracy, and timing of all those things, we actually started taking these prototype TRE systems and putting them out into the field,” Herndon recalled.⁴⁰ At the time, in the mid-1980s, Herndon still was an electrical engineering student at the University of Maryland, working as a co-op student but also feeling like a genuine member of an exciting, big technology development project. In 1986, he became a full-fledged NCST engineer.

By then, TRE units had already been passing important tests in the field. In 1984, Collier noted in an interview, a Spruance-class destroyer successfully received tactical signals from LIPS 2 with a prototype TRE.⁴¹ A second successful demonstration unfolded aboard the aircraft carrier USS *Midway*. These helped to whet the appetite of Navy leadership for the tactical use of satellite intelligence data.⁴² So rather than serving merely as a technology demonstration platform, LIPS 2 was designated as an operational tactical data relay system and served that role for eight years.

Integral to this capability was the development of a specialized broadcast format by which tactical data could be transmitted to TRE-equipped platforms. “Guys at NRL chaired the brain trust” of collaborating engineers by which this broadcast format, which became known as TADIXS-B (Tactical Data Information Exchange Subsystem B), was devised and deployed in the mid-1980s, recounted Collier.⁴³

This would be broadcast from “bent pipes” on LEO platforms, including LIPS 2, and FLEETSATs, which were a series of Navy communications satellites in operation beginning in the late 1970s. Collier credits NOSC engineer James Wangler and Commander Matt Rogers, a SPAWAR project manager, for figuring out that it would be possible to essentially embed TADIXS-B broadcasts as low-intensity signals at a frequency tuned away from the main center frequency of FLEETSATs. That way, it became possible for an existing satellite system to serve as a crucial means for leverag-

ing intelligence data into tactically useful information for the fleet. Key here, Collier noted, is that TADIXS-B would be unobtrusive and would not interfere with other mission-critical FLEETSAT operations.

Fully in on this development, added Collier, was an NRL team under Eisenhower's wing that included Herndon, Robert Burdett, and Jerry Phillips, and supervised by Andy Fox, a branch head within NCST's Space Systems Development Department. This team devised error-correction and other signal-processing protocols to accommodate for changes that the weak signal would undergo as it passed up to and back from the satellite through the ionosphere and onward to Tactical Receive Equipment. Heaping onto the challenge here was the restriction that no additional receive antennas could be installed on ships that would be dedicated to receive the TADIXS-B-based broadcast; the system would have to work with antennas already on the highly packed vessels. The broadcast channels developed for the TADIXS-B signal format was dubbed "TRE and Related Application (TRAP)" and its association with the end-point TRE units took on the acronym TRAP/TRE, often articulated as "trap tree." This is an arena unmercifully rife with acronyms, which at times become nested into two-tier acronyms.

Once in place, the system enabled essentially any ELINT intercept to be relayed to any platform in the world that had a TRAP/TRE system or an equivalent. According to Collier, NRL established a "control node" on its Washington, DC, campus, which operated for a number of years. "It was so successful and so good," he said, that the TRAP broadcast was modified in the early to mid-1990s to an even more widely accessible one that became known as the Integrated Broadcast System (IBS). The IBS also opened the way to consolidating multiple transmission and receive formats and broadcasts into one universal broadcast that all of the military services could use.

In the heart of yet another box that proved crucial in expanding the reach and tactical value of intelligence, surveillance, and reconnaissance (ISR) data is an NRL-developed On-Board Processor (OBP). In its initial deployment in space in 1996, according to an NRL account of the device, it proved to be "100 times more capable than anything else flying" and provided "real-time situational awareness information to military units located throughout the world."⁴⁴ To achieve that scope, the primary designers of OBP—Andy Fox, Dave Petit, and F. Brad Kuhn, Jr.—made sure it could relay data to a range of receive radios, among them Navy TREs, Army Commander's Tactical Terminals and SUCCESS Radios, and Air Force/USSOCOM Multi-Mission Advanced Tactical Terminals. The team took the OBP from the concept state through system engineering, to hardware and algorithm development, to fabrication, testing, and deployment.⁴⁵

There was powerful impetus to push the tactical angle. "The satellites were so prolific in the amount of data they gathered," said Collier, that without augmenting the system with new C4ISR tools that could rapidly handle and parse the data into actionable information, "the fleet just wouldn't be able to handle it. The satellites were,

in a sense, too good.” To leverage that goodness into as much tactical value as possible would require the ability to automatically gather data from diverse sources, fuse and correlate the data (geographically and in time, for example), and then display the resulting information on specialized terminals that, in Collier’s words, “would allow users aboard ship and elsewhere to deal with the large number of [threat] reports coming aboard. Up until we started developing these terminals, in a prototype environment, sailors had to read the reports, determine if they were relevant to the ship’s location and then plot them on plastic displays, writing backward from behind the displays.”⁴⁶ Added Collier, the sheer volume of reports derived from satellite-based and other intelligence sources “resulted in many of them being ignored” and a sense on board that the incoming information was more of “a burden rather than a God’s eye view of the ocean to aid them.”⁴⁷

In an effort to round up the funding required for developing these C4ISR tools, so as not to squander the vast amount of data that ISR assets were relentlessly gathering, Collier, NCST leaders, and other partners called on Navy flag officers to “beckon for the equipment” to their superiors who would have to approve the use of such funds. Along these lines, Collier noted, “we were working with the Navy TENCAP Office to demo the tactical capability.”⁴⁸

Rather than calling for production proposals for building TRE units, which would be costly and take years, engineers at the Naval Ocean Systems Center built and assembled roughly 100 of the units during the late 1980s.⁴⁹ TREs generally were installed aboard naval ships in the form of rugged, appliance-sized racks with receivers, cryptographic cards, and processors to orchestrate reception of TRAP broadcasts.

As TREs proliferated and proved valuable to the operational fleet, they caught the attention of other military services, which then turned to NCST for help in procuring similar field-level access to satellite data. The first extension, with development funding from the Air Force, inspired the TRE team at NCST, under the supervision of Eisenhower, to miniaturize TRE equipment so that it was suitable for aircraft. This was a time when electronic engineers were packing ever more integrated circuitry—and thereby ever more computational, signal, and general digital processing power—into less and less space. For their part, the NRL engineers expressed that trend in tactical receive equipment by designing in the 1990 time frame the Multi-Mission Advanced Tactical Terminal, or MATT, which the U.S. Special Operations Command asked NRL to develop.⁵⁰ Herndon pointed out that the acronym MATT was chosen in homage of then Commander Matthew Rogers, the program manager, who was impressed by the way the Navy was getting intelligence information to the floating fleet and wanted the same capability in the cockpits of tactical aircraft. “He worked to get this project funded,” noted Herndon.⁵¹

In 24 months, the NRL team managed to deliver the MATT prototype. Its face was about the size of a hardcover book in a housing that was 19 inches deep, which is to say it was small for the function it delivered. It could receive, decrypt, and

process intelligence data that had wended its way from various sources, including classified ones, through the network of ground stations, ULCER units, and LEO and geosynchronous (GEO) communications satellites, all the way to the gray, electronic-card-filled MATT boxes.



Downsized Tech. By miniaturizing appliance-size Tactical Receive Equipment terminals into the unit shown—the Multi-Mission Advanced Tactical Terminal, or MATT—NRL engineers were able to extend the value of tactical information from satellites and other assets to aircraft. (Source: *matt-p1*, *Federation of American Scientists*)

“The successful evaluation of the MATT led to the milestone decision for full-rate production and transfer of the technology to industry as the Airborne Joint Tactical Terminal (JTT),” according to an NRL account of its own major achievements.⁵² “MATT filled a need for a miniaturized multifunction radio and processor that provides near-real-time national intelligence data to field commanders and tactical fighters.” More than that, MATT, with its multiple receive channels, could combine the intelligence data with local “theater data” to help with target selection. Rather than residing out there in the orbiting periphery, these end-user terminals were hands-on tactical oracles on the inner periphery of the overall network.

“The MATT had the capability of receiving four intel broadcasts simultaneously from different [sources],” Eisenhower pointed out in an interview, adding that the terminal also delivered on the “Multi-Mission” part of its name.⁵³ The first MATTs were ready in 1991 and certified two years later by the National Security Agency (NSA) for meeting cryptologic and security standards.⁵⁴ In one of their airborne roles, MATTs became standard equipment in EA-6B aircraft whose mission is to gather electronic intelligence, sometimes on “wild-weasel-like” runs. In these missions, pilots deliberately fly the aircraft over an adversary’s air space to elicit signals from various radar and other optical and electromagnetic threats within range and then fire missiles to destroy the sources of those signals.

MATTs also became standard equipment “in a lot of ground operations,” Herndon added.⁵⁵ The prototype MATT units were built under NRL oversight by a consortium of support contractors including Assurance Technology Corporation, headquartered in Carlisle, Massachusetts, and Aeronix and Symmetrics Industries, both headquartered in Melbourne, Florida.⁵⁶

In the same time frame when the first MATT units were getting installed, the Air Force called upon the NCST electronics team to oversee development of a specialized high-speed digital modem for F-16 fighter jets. The Air Force wanted a compact unit that would enable pilots to automatically reform various types of relevant data

coming into the cockpit via the MATT (on a nearby F-4) into information that could precisely inform and guide F-16 weapons systems, including radar-seeking HARMs (High Speed Anti-Radiation Missiles). Known as the Improved Data Modem (IDM), and developed under the supervision of program manager Bob Burdett, the box “established the first digital link capability between fighter aircraft, and between fighter aircraft and ground units,” according to an NRL account of the technology.⁵⁷

Herndon credits Jerry Phillips with discerning the opportunity for NCST to get into development work that led to the successful IDM project. Phillips learned about a requirement by Army Aviation, an administrative branch within the U.S. Army, to modernize an automatic targeting system that it had on its Kiowa Warrior and Apache helicopters. Recalled Herndon, “Phillips literally pulled two modules out of [another communications device his team had developed]⁵⁸ and repackaged them, and reworked some of the software, with help from a couple of contractors, and that was how the IDM was born.”⁵⁹ And that became the basis of a proposal to the Army. At the time, however, the Army did not have the requisite funding to immediately go ahead with the NRL proposal.

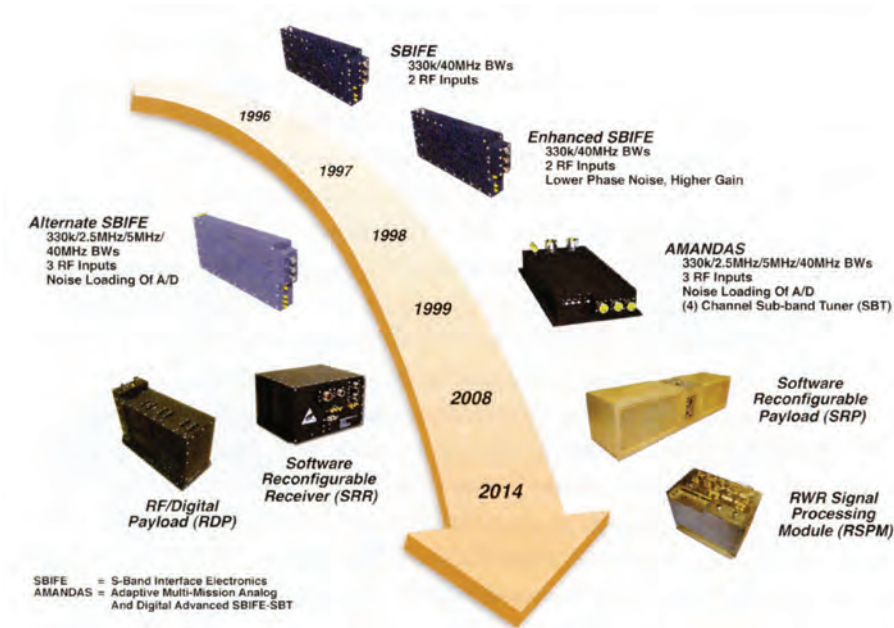
That did not stop Phillips and his team moving forward by way of the Air Force. When the Air Force heard about the NRL proposal, it provided the funding necessary to develop an aircraft version of the IDM, in this case primarily for F-16s.⁶⁰ So a project originally instigated by Army Aviation ended up as Air Force hardware.

“What this box does is input digital data into an existing analog radio that then transmits it to another platform thereby allowing you to relay digital targeting information,” Eisenhower explained.⁶¹ “The IDM allowed digital information to be transmitted in the background on the same frequency the pilots were using to communicate and at the same time,” added Collier.⁶² “The IDM provides pilots the ability to communicate information in seconds (or less) what would otherwise take several minutes by voice, thus minimizing exposure to enemy jamming and/or transmission interception,” according to an official NRL account, which added that the IDM was installed on many platforms, including Air Force F-16s and the Navy’s carrier-based EA-6Bs.⁶³

The McLean, Virginia-based firm Innovative Concepts (ICI) developed production models of the IDM based on the NCST team’s preproduction models. Herndon added that these units were useful during development for “aircraft certification, air worthiness and other associated testing, all of that kind of stuff.”⁶⁴ A competitive contract was ultimately let for “full rate production” to Symmetrics Industries. “This transition from the laboratory to industry was exemplary and thousands of units were produced,” said Collier.⁶⁵

All the while, the world had been turning and sometimes dramatically, as on August 1990 when Iraq invaded its neighbor Kuwait. That quickly led President George H.W. Bush to authorize Operation Desert Shield, a military buildup in preparation for Operation Desert Storm, which began as an air war on January 17, 1991.

The Department of Defense already was concerned about tactical communications problems in battlefield settings. “Existing tactical radios lacked interoperability and could not be easily integrated on military platforms,” according to an NRL account.⁶⁶ “Comprehensive communications across the battlefield required the simultaneous use of many different radios.” A potential solution to this problem was to build a novel “software defined radio,” or SDR, in which one box could emulate, by way of software, a large range of radio types that operate on a diversity of radio frequency bands and signal modes, or waveforms. It was a technology waiting for a crisis to usher it toward hardware, and engineers at NCST were well positioned to make it so.



Chameleon Radio. Rather than building individual radios for uses ranging from voice communication to data transfer to navigation, why not build one radio that can become all of these by way of onboard software that can orchestrate the function changes? The chart, from NRL contractor and technology development partner Assurance Technology Corporation, shows the evolution of this technology, known as software defined radio. (Source: SDR_ACT, courtesy of Assurance Technology Corporation)

The ground war component of Desert Storm proceeded so swiftly that the U.S. Army found it to be impossible for its multi-tent, multi-truck, multi-workstation, multi-officer Tactical Operations Center (TOC) to keep up with the fast-moving war-fighters on the ground. A TOC is all about command and control of operating forces in a theater of war. There was no major remedy for the situation within the six weeks before a cessation of hostilities on February 28,⁶⁷ but the deficiency was not lost on military leadership. The Desert Storm experience revealed to the Army that it needed an airborne command and control capability in anticipation of future conflicts involving swiftly moving forces. Software defined radio technology would only add more tactical power to such a capability.

An early incarnation of software defined radio emerged from a late-1970s initiative by the U.S. Air Force Avionics Laboratory initiative known as the Integrated Communication, Navigation, Identification and Avionics (ICNIA) program.⁶⁸ The first flight test of an SDR radio within the ICNIA program took place in 1992, just a year after Desert Storm. A few years before that test, the Air Force Research Laboratory paved some of the way to that test flight by developing a processor that could simultaneously manage several communications waveforms—a term that refers to digitally definable communications frameworks encompassing, among other traits, transmission frequency information, how the frequency is modified (as in amplitude modulation or frequency modulation, AM or FM), and coding and encryption schemes. The approach was modular too, so that the same architecture could be scaled up to handle more and more waveforms within the same box. It was just a matter of swapping out or adding more software.

Examples of waveforms that could be accommodated within the same SDR system (though maybe not all at once) include: UHF—Ultra High Frequency communication, the standard voice transmission method; WNW—Wideband Network Waveform, a single RF networking protocol waveform with variations depending on spectrum allocation and access rights; IFF—Identification Friend or Foe, which uses a protocol contained in the transmission to autonomously determine whether a contact is associated with an ally and not an enemy; ILS—Instrument Landing System, which provides information relevant to a pilot landing his or her aircraft; TACAN—Tactical Air Navigation, which gives a pilot information as to his range (distance) and bearing (direction) to or from a beacon; and TTNT—Tactical Targeting Network Technology, a waveform associated with a network that supports the goal of locating, identifying, targeting, and attacking the enemy.⁶⁹

Well before that first flight test within the ICNIA program, and before the term “software definable radio” came into vogue, NRL’s space technology cadre already had developed an expertise in the technology, though they first were applying it in low Earth orbit rather than in the lower atmosphere where military aircraft operate. “If we put a radio into space, we had to be able to configure it,” noted Herndon. “You had to be able to put waveforms into that radio to do new things.”⁷⁰ And the more entrepreneurial researchers within NCST—among them Eisenhower, Phillips, and Herndon—were eager to take that skill set and technology to new markets.

To the Army, for instance. In 1994, the Army took steps to turn into hardware its need for mobile and agile command and control platforms. Having worked with NRL previously to develop the IDM, it asked NRL to convert a UH-60 Blackhawk helicopter into a stand-alone Army Airborne Command and Control System, or A2C2S. “The idea was that the commander, if he had to, could go aboard a Blackhawk helicopter with his intel guy, logistics guy, maybe one or two others, and each would have an identical workstation separately configured to support the function each guy is responsible for,” explained Collier. “And then they could keep flying

to new locations to keep up with a fast-moving battle line.⁷¹ What's more, if that command and control helicopter were taken out of the loop by accident or enemy action, another similarly equipped copy could readily take its place, conceivably within minutes.



Command Control. As NCST diversified its portfolio of research and development in the 1990s, its engineers became adept at building miniaturized tactical information systems that could, for example, turn a helicopter into a Tactical Operations Center that previously would have been ground based, far less agile, and required far more equipment. Shown here (with NRL's main administrative building in the background) is a UH-60 helicopter rendered into an Army Airborne Command and Control System (A2C2S), along with a view of Command and Control personnel at onboard tactical workstations. (NRL photos 99-098(11).jpg and 99-000122 (25).jpg)

“The challenge was to take this big conglomeration of trucks and vans that forms an Army Tactical Operations Center in the field and integrate all of that functionality into a small Blackhawk helicopter,” explained Collier. “That is what A2C2S was. And NCST did that.”⁷² The requirements called for a system that could support 37 heritage radios,⁷³ a massive amount of equipment that previously required a tent and truck city. And this is where the software defined radio innovations came in, in particular a box that Burdett, Herndon, Robert Higgins, Jerry Phillips, and their colleagues called the Joint Combat Information Terminal (JCIT).

JCIT was the same size as a MATT box but had eight radio channels, appropriate cryptologic function, and adequate processing power to emulate any number of radios. Through the mediation of software, the JCIT could, in principle, take “the place of the 37 heritage radios, demanding as a consequence only a fraction of the latter’s size, power and weight,” stated an NRL summary of the achievement.⁷⁴ “We could load different waveform software onto it so that it could emulate all of these radios and we were able to achieve with this integrated radio something like an 80 percent size reduction compared to the existing radios,” explained Herndon.⁷⁵ In practice, the government terminated JCIT development at a point at which the units could emulate up to eight of these.

What in the past had taken dozens of racks of equipment—each one devoted to the specific radio waveforms associated with, say, intelligence data, voice communication, or command and control signals—now became compact enough to fit in the little available space inside a Blackhawk helicopter. The NCST team proved it could be done with a Blackhawk helicopter that the Army had delivered to the lab. “We took a Blackhawk helicopter and filled it up with all of the crypto, all of the radios, all of the

boxes you need to be airborne command and control,” said Eisenhower, who assigned Higgins as the lead design engineer on the project. In an extensive series of tests in the mid-1990s at Ft. Hood, Texas, Higgins, Herndon, and other test engineers and software developers worked the kinks out of the system. Herndon served as a “technical flight observer” aboard a UH-60 helicopter.⁷⁶ “I was helping the guys learn [what would become the A2C2S] system and operate it. This is where we really start to hit a C4I system” for the warfighter, Herndon said.⁷⁷

Subsequent tests with the Blackhawk and other military platforms proved the concept that a full-service command and control function, such as an Army TOC, could be miniaturized and made mobile enough so that the command and control center could be essentially as agile and flexible as individual soldiers on the ground. “Would anyone ever have thought that the Navy Center for Space Technology would be building the Army’s airborne command and control system,” Eisenhower pointed out with amusement and noticeable satisfaction. “But you take a bunch of competent and good engineers, put them together and create the right work environment, and you would be amazed at what you can get.”⁷⁸

The dramatic reductions in the weight, space, and power needs that the ongoing feats of electronics miniaturization made possible fanned the engineering and entrepreneurial flames for NCST’s C4ISR experts. From MATT, for one, NCST’s C4ISR team spun out a lineage of derivative boxes in the 1990s and beyond that just kept expanding the potential reach of tactical information. For example, they developed the Briefcase MATT, or BMATT, for special operations forces, although it never got much traction. Only a few copies were ever built. Though BMATT was not a field success, Herndon and his colleagues leveraged the lessons learned from it into a program ominously named Radiant Hail.

As part of this program, the NCST engineers heaped more into the mix by integrating into these boxes computer-based, three-dimensional visual renderings, in this case of battlefields and other militarily relevant landscapes. Using photoreconnaissance feeds from, for example, high-flying U-2 aircraft, whose function now also can be served by drones, “you could lay down a tactical battlefield picture and then do a 3-D fly-through of it,” Herndon said, noting that this was a time when this was only possible with cutting-edge graphics processors. “So we married this 3-D terrain processing with the MATT and were able to show a radar threat on map [on a visual display], through 3-D visualization where that threat had visibility, so that you could literally plan an entire ingress and egress,” explained Herndon. “Radiant Hail was a huge success.”⁷⁹

There was another innovation built into Radiant Hail that would expand the tactical value of yet more of the C4I boxes that NCST engineers could design and that could provide warfighters with previously out-of-reach capabilities. Radiant Hail units had the ability to receive Tactical Broadcast System (TBS) signals from U-2s and other sensor platforms. “Radiant Hail yielded the first TBS capability [for warfight-

ers], and it was back-ended into the MATT,” opening up a pathway, said Herndon, “to a whole family of receivers.”⁸⁰

In an ongoing project at the time with Army Aviation, stemming from the command and control shortfalls that became apparent during Operation Desert Storm, the NCST team was finessing its technology to bring tactical data into the Army’s helicopters, including the Apache, Kiowa, and UH-60, and ultimately into the planned state-of-the-art Comanche, which ended up getting canceled in 2004 before any were built.⁸¹ These technology developments and testing efforts amounted, said Herndon, “into a proof of concept that you could in fact do command and control from these helicopters.”⁸²

That NCST would be developing a software defined radio and other C4I-related and tactical communications systems for end users outside of the Navy required both chutzpah and competence. “It was other peoples’ money,” Eisenhower said, referring to the Army and other sponsors who followed suit in turning to NCST for its C4ISR wares, and “if they were going to give us money, and it was the only money they had for a particular need, then we damn well better succeed. If we didn’t, someone was going to take our head off.”⁸³ As the head of NRL’s Space Systems Development Department, and as one of the first of NCST’s leaders with a sense of urgency for the Center to forge alliances with more sponsors, Eisenhower made it his mission to make this work.

And so did the rest of the C4I team members. The NCST team’s work on the A2C2S program—the mobile command and control project for the Army—under the leadership of Robert Higgins, instilled in them the imperative of keeping technology as small, lightweight, and power efficient as possible. And, with its entrepreneurial spirit, the NCST team knew that if it were going to get its C4I technology accomplishments into more of the Department of Defense’s airborne and ground platforms, it was going to have to do so by way of existing tactical radios, especially ones in aircraft. These radios had their own names and acronyms like HAVEQUICK and SINCGARS, the latter of which stands for Single Channel Ground and Airborne Radio System.

As it turned out, the JCIT, which was envisioned to become a communications terminal that all of the military services could adopt, never went into production. Instead, many of its innovations and concepts were subsumed in a more comprehensive and ultimately trouble-plagued, Department of Defense-wide program known as Joint Tactical Radio System (JTRS). Even so, the same C4I technology lineage that went from LIPS to TRE to MATT to JCIT to the Blackhawk-hosted A2C2S opened pathways throughout the 1990s and the first decade of the new millennium for an ongoing series of technology transfers to industry manufacturers. This progression yielded a veritable catalog of receiving terminals, data handling processors, interfaces, and other C4ISR components. And these were assembled into systems tailored for a multitude of airborne and ground-based platforms, among them CH-47 Chinook

heavy-lift helicopters, agile Blackhawk helicopters, F-16 fighter jets, the much larger Joint Surveillance and Target Attack Radar System (JSTARS) aircraft, Abrams tanks, and the U.S. Marine Corps' Light Armored Vehicles (LAVs) and Assault Amphibious Vehicles (AAVs).⁸⁴

“The JCIT program was the leverage point” for all of this, noted Herndon. “It showed the power of being able to have multiple radios of different frequency bands integrated together in the same command and control environment.”⁸⁵ From the perspective of Herndon, Eisenhower, and others who were working on C4I technology at NCST, JCIT had what it took to become the long-coveted universal tactical radio throughout the Department of Defense.

The Department of Defense-wide JTRS program began with good intentions and promised enormous potential payoff. After all, each year for decades, the Department of Defense had a growing sense of urgency for new-generation communication systems that could accommodate the expanding diversity of defense- and warfighting-relevant categories of RF signals, among them voice, intelligence, tactical data, and imagery. It had been clear for many years that the parallel but independent development of many such systems by the Air Force, Navy, Army, smaller organizational units, and other military and government services was leading to duplication of effort and expense.

This concern led to the establishment of the joint U.S. government JTRS program to, in Eisenhower's words, “solve the problem once.” The problem in this case was to develop an architecture and technology that would meet requirements for multimedia communication and networking throughout the military sector for the coming years. It was a vision to reduce a veritable “Tower of Radio Technology Babel” into a coherent radioscape. Moreover, in the late 1990s, as the Internet was in its ascent, military commanders were reformulating their visions of the future for “net-centric” warfare in which a military version or modification of the Internet would be integral to strategic planning and tactical operations. This too would have to become part of the essentially universal communications systems the Department of Defense envisioned. The JTRS program evolved into an enormous and ultimately overly ambitious technology development project that proved too unwieldy to manage with foresight or competence. It would fail to achieve its goals.

According to an analysis of the troubled JTRS program that the U.S. Government Accountability Office (GAO) released in September 2006, one cause of failure was a relentless sequence of additions and changes by the partners of the joint program to the required capabilities of the systems. This practice ultimately led to results such as “mobile” units that, as one wry observer put it, “weighed as much as a drill sergeant.”⁸⁶ The vision to deploy software defined radio technology and a massive, multibillion-dollar, 15-year Department of Defense program to realize the vision took a severe hit in 2011 when the Army canceled a major JTRS subprogram, known as the Ground Mobile Radio (GMR). The program took another huge hit in 2012 when the

Pentagon shut down its central JTRS office and shifted future JTRS acquisition duties to the Army within the auspices of a newly formed Joint Tactical Networking Center.⁸⁷

Getting shut out of the ill-fated program also forced NCST's C4I team to think even further out of the box than it had before when it was bold enough to think that non-Navy military services actually would even consider technologies designed by Navy engineers. But the technologies the team had developed were too good to let die on the vine. "For the first time," said Herndon, "really and truly, we had all of these capabilities that would not only help warfighters, but that were extendable to so many other issues related to land-mobile types of communications needs." It was a matter of survival, in part, because the flow of R&D money for C4I would surely diminish greatly if the team could not find new partners and markets for its technology. The same ability the C4I team had demonstrated to tap into all kinds of data, intelligence, and communications sources and types that underlay, for example, the A2C2S, could help solve vexing problems in the civilian sector. Said Herndon, "We started reaching out to the National Institute of Justice and other places that were talking about interoperability problems in the civilian world, in police, fire, emergency, and medical services."⁸⁸

In pursuit of these partnerships, in August 2001, NCST's C4I researchers and managers held a discussion with officials at the World Trade Center's Office of Emergency Management. The discussion focused on interoperability and doing communications in a major infrastructure outage. "We got a tour of the command center on the 23rd floor of Building 7" of the WTC complex, Herndon recalled. It was one month before September 11, 2001.

¹ Robert Eisenhauer, interview with author, March 12, 2012.

² Robert Eisenhauer, interview with author, March 12, 2012.

³ Robert Eisenhauer, interview with author, March 12, 2012.

⁴ Art Collier, personal correspondence during interview with Robert Eisenhauer, March 12, 2012.

⁵ Art Collier, personal correspondence during interview with Robert Eisenhauer, March 12, 2012.

⁶ Applied Research Laboratory, The Pennsylvania State University (eds.), *From the Sea to the Stars: A Chronicle of the U.S. Navy's Space and Space-related Activities, 1944–2009* (revised and updated edition, 2010), p. 76, <http://www.history.navy.mil/content/dam/nhnc/browse-by-topic/exploration-and-innovation/navy-and-space-exploration/FromTheSeaToTheStars/FromTheSeaToTheStars%20-%202010ed.pdf>.

⁷ *From the Sea to the Stars*, p. 76. The TENCAP office also was designated as OP 943E and the Office of the Director of Navy Command and Control also was designated as OP 94.

⁸ *From the Sea to the Stars*, p. 77.

⁹ *From the Sea to the Stars*, pp. 111–112.

¹⁰ Chris Dwyer, interview with author, February 19, 2012.

¹¹ Ronald L. Potts, *U.S. Navy/NRO Program C Electronic Intelligence Satellites (1958–1977)*, LEO Systems Program Office, National Reconnaissance Office, September 3, 1998, pp. 168–170.

- ¹² Robert Eisenhower, interview with author, March 12, 2012.
- ¹³ Robert Eisenhower, interview with author, March 12, 2012.
- ¹⁴ Robert Eisenhower, interview with author, March 12, 2012.
- ¹⁵ Robert Burdett, interview with author, January 22, 2013.
- ¹⁶ Chris Dwyer, interview with author, February 13, 2012.
- ¹⁷ Lee Hammarstrom, draft of memoir (unpublished), prepared in late 2013.
- ¹⁸ James Winkler, *My Career at the Naval Research Laboratory*, draft given to author in 2012, p. 61.
- ¹⁹ Winkler, *My Career at the Naval Research Laboratory*, p. 61.
- ²⁰ Bob Eisenhauer, interview with author, March 12, 2012.
- ²¹ Art Collier, personal correspondence, April 2014.
- ²² The phrase is attributed to NASA Administrator Daniel Goldin, who ran the agency from 1992 to 2001; see http://history.nasa.gov/dan_goldin.html.
- ²³ Lloyd Carter, “NRL Team Converts Protective Shield Into a Spacecraft,” in *Labstracts*, Naval Research Laboratory, January 13, 1984.
- ²⁴ Winkler, *My Career at the Naval Research Laboratory*, p. 61.
- ²⁵ Winkler, *My Career at the Naval Research Laboratory*, pp. 61–62.
- ²⁶ Winkler, *My Career at the Naval Research Laboratory*, pp. 61–62.
- ²⁷ See, for example, Ivan Amato, *Pushing the Horizon: Seventy-Five Years of High Stakes Research and Technology at the Naval Research Laboratory* (Washington, DC: Naval Research Laboratory, 1998).
- ²⁸ Amato, *Pushing the Horizon*, p. 70.
- ²⁹ Winkler, *My Career at the Naval Research Laboratory*, p. 69.
- ³⁰ *Labstracts*, NRL February 5, 1988 and September 29, 1988.
- ³¹ Winkler, *My Career at the Naval Research Laboratory*, p. 69.
- ³² Winkler, *My Career at the Naval Research Laboratory*, pp. 71–72.
- ³³ Winkler, *My Career at the Naval Research Laboratory*, pp. 71–72.
- ³⁴ Chris Herndon, interview with author, February 4, 2013.
- ³⁵ MDR stood for Moderate Data Rate.
- ³⁶ Chris Herndon, interview with author, February 4, 2013.
- ³⁷ Art Collier, personal communication, April 2014.
- ³⁸ Chris Herndon, interview with author (for *Pushing the Horizon*), February 1998.
- ³⁹ Art Collier, personal communication, April 2014.
- ⁴⁰ Chris Herndon, interview with author, February 4, 2013.
- ⁴¹ Art Collier, in interview with Peter Wilhelm and the author on May 17, 2013; Art Collier, interview with author, January 29, 2013.
- ⁴² Art Collier, interview with author, January 29, 2013.
- ⁴³ Art Collier, interview with author, April 22, 2012.
- ⁴⁴ Naval Research Laboratory, 75th Anniversary: Awards For Innovation, NRL/PU/1001--98-359, June 1998, p. 68.
- ⁴⁵ Naval Research Laboratory, 75th Anniversary, p. 68.
- ⁴⁶ Art Collier, personal correspondence, April 2014.
- ⁴⁷ Art Collier, personal correspondence, April 2014.
- ⁴⁸ Art Collier, interview with author, April 22, 2012.
- ⁴⁹ *From the Sea to the Stars*, p. 126.
- ⁵⁰ Naval Research Laboratory, “The U.S. Naval Research Laboratory (1923–2005) Fulfilling the Roosevelts’ Vision for American Naval Power,” NRL/MR/1001--06-8951 (Washington, DC: Naval Research Laboratory, March 6, 2006), p. 55.
- ⁵¹ Chris Herndon, interview with author, February 4, 2013.
- ⁵² NRL, “Fulfilling the Roosevelts’ Vision,” p. 55.
- ⁵³ Bob Eisenhauer, interview with author, March 12, 2012.
- ⁵⁴ NRL, “Fulfilling the Roosevelts’ Vision.”

- ⁵⁵ Chris Herndon, interview with author (for *Pushing the Horizon*), February 1998.
- ⁵⁶ Art Collier, personal correspondence, April 2014.
- ⁵⁷ NRL, "Fulfilling the Roosevelts' Vision," p. 55.
- ⁵⁸ Herndon was referring to the ACIM, or Advanced Communications Interface Module.
- ⁵⁹ Chris Herndon, interview with author, February 4, 2013.
- ⁶⁰ Art Collier, personal correspondence, April 2014.
- ⁶¹ Robert Eisenhauer, interview with author and Art Collier, March 12, 2012.
- ⁶² Robert Eisenhauer, interview with author and Art Collier, March 12, 2012.
- ⁶³ NRL, "Fulfilling the Roosevelts' Vision," p. 55.
- ⁶⁴ Chris Herndon, interview with author, February 4, 2013.
- ⁶⁵ Art Collier, personal correspondence, April 2014.
- ⁶⁶ NRL, "Fulfilling the Roosevelts' Vision," p. 58.
- ⁶⁷ Army Live: The Official Blog of the United States Army, "A Timeline of Operation Desert Storm," <http://armylive.dodlive.mil/index.php/2013/02/operation-desert-storm/>.
- ⁶⁸ David Burrill, "Evolution of Software Defined Radios in Military Aircraft Communications," (Washington University: 12/6/2006), accessed at <http://www.cs.washington.edu/education/courses/csep590/06au/projects/radios.doc>; Minh Nguyen, "Software Radio (R) Evolution and Its Application to Aeronautical Mobile Communications," Integrated CNS Conference, May 19–22, 2003, accessed at http://www.mitre.org/work/tech_papers/tech_papers_03/nguyen_radio/nguyen.pdf.
- ⁶⁹ Burrill, "Evolution of Software Defined Radios in Military Aircraft Communications."
- ⁷⁰ Chris Herndon, interview with author, February 4, 2013.
- ⁷¹ Art Collier, personal correspondence, April 2014.
- ⁷² Art Collier, personal correspondence, April 2014.
- ⁷³ NRL, "Fulfilling the Roosevelts' Vision," p. 58.
- ⁷⁴ NRL, "Fulfilling the Roosevelts' Vision," p. 58.
- ⁷⁵ Chris Herndon, interview with author, February 4, 2013.
- ⁷⁶ Robert Eisenhauer, interview with author and Art Collier, March 12, 2012.
- ⁷⁷ Chris Herndon, interview with author, February 4, 2013.
- ⁷⁸ Robert Eisenhauer, interview with author and Art Collier, March 12, 2012.
- ⁷⁹ Chris Herndon, interview with author, February 4, 2013.
- ⁸⁰ Chris Herndon, interview with author, February 4, 2013.
- ⁸¹ <http://nation.time.com/2012/05/25/real-lessons-from-an-unreal-helicopter/>.
- ⁸² Chris Herndon, interview with author, February 4, 2013.
- ⁸³ Robert Eisenhauer, interview with author and Art Collier, March 12, 2012.
- ⁸⁴ This list appears in many places, but a good start would be with "Capabilities Overview" presentations prepared by ATC (Assurance Technology Corporation), which has worked with NCST engineers on many projects.
- ⁸⁵ Chris Herndon, interview with author, February 4, 2013.
- ⁸⁶ Government Accountability Office, "Defense Acquisitions: Restructured JTRS Program Reduces Risk, but Significant Challenges Remain," GAO-06-955 (Washington, DC, September 2006).
- ⁸⁷ See, for example, <http://www.nextgov.com/mobile/2012/08/pentagon-shutters-joint-tactical-radio-system-program-office/57173/>.
- ⁸⁸ Chris Herndon, interview with author, February 4, 2013.

16

C4ISR 2.0

“Everything has changed” was a commonly heard phrase in the wake of the terrorist attacks on September 11, 2001. To be sure, the nation’s perspective on the nature and diversity of its enemies changed drastically and with it changed the country’s sense of urgency for intelligence, communications, and defense needs. As terrorism, rather than state-based enmity, became the focus of national defense thinking—so much so that the government would undergo a massive reorganization to accommodate the new Department of Homeland Security—any practice, protocol, or technology that could bring the military, intelligence, and first-responder communities closer to a state of omniscience about “the threat space” became more interesting to the defense and homeland security communities.

Additionally, improving the ability to compensate for massive failures—due to natural and human-wrought disasters—in the communications infrastructure shot to the top of the national priority list. In a September 2004 article in *Signal* magazine, a publication of the Armed Forces Communications and Electronics Association, retired Air Force Colonel Michael D. McDonald told a reporter that the White House had experienced communications difficulties during the terrorist attacks three years earlier. “It was the ‘Mother’s Day Effect,’” he was quoted as saying. “Everyone wanted to communicate at the same time. The communications systems were inadequate to meet the needs of responding to the threat ... A lot of people think all the President needs to do is say ‘launch.’ Well, in order to do that, he’s got to have some kind of situational awareness, and that was the initial challenge that we had on 9/11.”¹

“The first question was, What the heck is going on?” concurred Chris Herndon, the former NRL employee who worked on C4ISR projects for NCST. And answering that question, no matter what the crisis might be, is all about developing and deploying communications capabilities that remain reliable even under extraordinary circumstances.

This was a familiar state of mind for the Naval Center for Space Technology, which celebrated its 15th anniversary in 2001. From its launch of the world’s first spy satellite in 1960 to monitor Soviet strategic air and missile defense radars, to its role in an expansive all-ocean surveillance system, to its military C4I work with the goal of packaging the nation’s intelligence capabilities into tactical information tools that can deliver to warfighters previously unimaginable levels of situational awareness, NCST has been all about emulating a God’s eye view regarding threats to the nation.

The airliner attacks by Al Qaeda operatives on 9/11 in New York and at the Pentagon, and the passenger-thwarted attack that ended with a no-survivor crash in the Pennsylvania countryside, hit the country like a modern day Pearl Harbor. The ability to identify and monitor potential adversaries, whoever they might be and wherever they might be in the world, at all times, immediately topped the list of the nation's technology development to-do list. For those at NCST who had been developing compact, mobile, and versatile C4I technologies in the military "sensor-to-shooter" paradigm, it was clear that this new heightened state of alert would open up new applications for integrated miniaturized packages of command, control, communications, computers, and intelligence (C4I), which they had first demonstrated the previous decade in, for example, the A2C2S system designed for the Army's Blackhawk helicopter.

The first glimmers of a wider role for NCST in the nation's civilian and homeland security C4I capabilities go back even further, to the 1980s when NRL's industry partners in NRO-sponsored programs started referring to the satellites as "orbiting peripherals" of a much larger intelligence and communications system. By the mid-1990s, it was possible to become an NCST employee and end up having little to do with the satellites that had been the focus of the organization and its lineage going back to Project Vanguard of the 1950s. "My history here at NRL has never been with space," Robert Roberts—a former Navy officer who left the service to earn an engineering degree before joining NCST in 1995 where he began working on the A2C2S demonstration program—said in an interview. "I don't have any working knowledge in the space aspect of NCST; it's all on the ground side," said Roberts, who since 2005 has been head of the Tactical Technologies Development Laboratory (TTDL),² which is housed in a windowless, multistory cube on the river-side of Building A59 on NRL's campus. Herndon was head of TTDL until Roberts took over.

More and more since the 9/11 attacks, Herndon initially and then Roberts and their respective colleagues, have been adapting technologies originally developed for Department of Defense purposes so they can be deployed for nonmilitary services that handle emergency situations or have a role in local, regional, or national security. Roberts' colleague George Arthur in NCST's C4I Branch, for example, worked on software and testing phases of the MATT (Multi-Mission Advanced Technical Terminal) in the 1990 time frame, but then later found himself applying his skill set to developing technologies for civilian sector emergency responders.³ One of them was the New York City Fire Department (FDNY), a connection that was initiated by Dave Derieux, a second-generation NRL employee who first started working at NRL in 1984 on a powerful laser project in the Plasma Physics Division. Derieux joined NCST in 1987 to become part of the team developing the Improved Data Modem (IDM) for fighter aircraft. From there, he worked his way up to become the Associate Superintendent of the Space Systems Development Department of NCST.⁴

The FDNY was looking to solve a problem that came to the fore during its response to the 9/11 jetliner attacks on the World Trade Center towers in lower Manhattan. At the time, FDNY was using a firefighter tracking system known officially as BF4 (for Battalion Form 4) and less officially as “the riding list.” During a response to a call, the names of firefighters on a truck would be written down in duplicate on a paper form. “One copy stayed on the clipboard on the truck; the other copy stayed in the pocket of an officer,” who was also on the truck, Arthur explained. “When the towers came down, they destroyed all of the equipment and killed so many people that they [FDNY] had no way of knowing who had been there. They didn’t ever want that to happen again.”⁵

At the invitation of the FDNY, Arthur and several NCST colleagues spent two days in New York City, visiting firehouses, rushing off to fires in the fire chief’s car, and getting a feel for how the department operated. At FDNY headquarters, the NCST contingent ended up around a table with FDNY’s Deputy Fire Commissioner Milton Fischberger. “We were just pitching some ideas back and forth, and out came the idea that we could put together an RFID [radio frequency identification] system” that could replace the BF4 system, Arthur recalled. By 2006, the NCST team had collaborated with FDNY to get half of the system—known as EBF4 (Electronic Battalion Form 4)—in place. With radio-emitting RFID tags attached to their gear and communicating with receivers at the firehouse, the system keeps accounts of when firefighters leave to respond to a fire and when they return. A key advance here is that firefighters’ names are stored away from the emergency location. “The complementary half of the system would track the firefighters when they are in the burning structure, and then you would be able to track them from the moment they left the firehouse to the moment they came back,” explained Arthur.

Along that line, Arthur and his colleagues fitted a handful of engine, ladder, and rescue rigs in Queens, New York, with RFID receivers that Arthur said he hoped would evolve into a tracking system throughout the city that will be able to keep tabs on firefighters throughout the entire duration of a response. As of 2014, fifteen vehicles had been fitted with the receivers.⁶ Even before that was in place, he noted, the RFID program yielded additional NRL/FDNY collaboration. “They liked our software so well that they asked us if we could expand it into an administrative tool that they could deploy citywide and that would allow them to do all of their shift planning. And we have done that,” Arthur said. “That went hot in 2009 and it is their standard planning tool now.”⁷

That the Naval Center for Space Technology would become a partner with a big city fire department might appear to be an enormous stretch, unless one considers two things: (1) so much of NCST’s portfolio, and the skill sets of its staff, has been centered on communications, and (2) the FDNY’s need for a better way to track its firefighters emerged out of what essentially was an act of war.

After 9/11, the reach of NCST's C4I team and its technologies would extend to other government organizations. One symbol of this work was a tan satellite communications truck that TTDL researchers had on hand on campus near the Potomac River, noted technician Bruce Morgan. Like Dave Derieux, Morgan's father had preceded him on the NRL campus, in his case as an officer with the Naval Security Group, which was associated with the spy satellite programs from which NCST would emerge. "After 9/11 happened, that vehicle was reconfigured," Morgan said.⁸



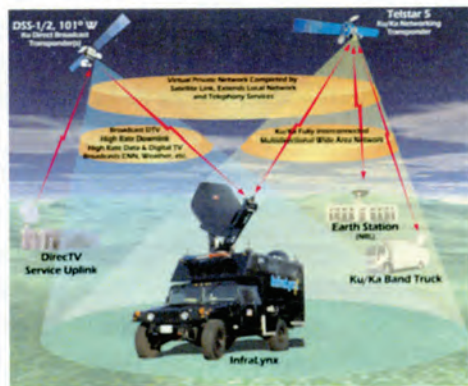
The Tan Truck. As symbolized by this tan truck in front of NRL headquarters, NCST became so adept at adapting its collective expertise in electronics, communications, miniaturization, logistics, and other areas that it became a go-to organization when the need for powerful stopgap communications services emerged due to natural disasters or hostile actions by terrorists or others. (NRL)

"We leveraged our ability to do [satellite communications] pretty much anywhere in the world, and all our work in radio communications and interoperability," said Herndon, who was Morgan's boss at the time.⁹ Within days of the collapse of the World Trade Center, NRL had assembled a team that could have restored services to the first responders on the ground in New York City.

"It wasn't pretty because we had put it together so quickly, but we clearly showed the capability of standing up a private cellular node, standing up land-mobile capabilities, and integrating all of that onto a common backbone, and then teleported that over a satellite so that you could draw a local dial tone ... at a disaster site," explained Herndon. The initial setup—before the team turned the tan truck into one of the most capable C4I hubs on four wheels—involved two Humvees at the lab, including one from another lab division, the Information Technology Division, which had a satellite dish on it. "So we used their satellite dish and Humvee, and our radio comms and our satellite modems, and cobbled together a two-truck version of what became InfraLynx," Herndon said, turning to the short form for the overall stand-in communications package that they dubbed "Infrastructure Linkage and Augmentation Sys-

tem.”¹⁰ The NRL team was getting ready to deploy the Humvees to Manhattan, but the Federal Emergency Management Administration (FEMA), Herndon said, “wouldn’t allow anybody else in that city at that point.”¹¹

Despite that red light for Ground Zero in New York City, the tan truck at the lab became a test bed and demonstration vehicle for taking compact and mobile C4I capabilities that NCST engineers and their partners had developed during the “sensor-to-shooter” campaign of the 1980s and 1990s and adapting it under the rubric of InfraLynx for use in nonmilitary but critical situations.¹²



Comms on Wheels. As the InfraLynx mobile communications technology proved itself, NRL began promoting it actively as shown with this page from an InfraLynx brochure. Also shown is the brochure image depicting the overall communications architecture and capabilities.

The swiftness to readiness that the NCST team demonstrated in the wake of the 9/11 attacks became a selling point. The C4I team was able to win over the office of the Chief of Naval Research (CNR), which provided the funding for outfitting a C4I concept vehicle that the team could take out on the road for demonstrations of its capabilities. “We integrated this black Humvee with a black satellite dish, and all of these software definable radios—and a bunch of Motorola radios and things like that—a private cell switch, and then we took it out on the road to show what interoperable comms could mean, especially when you integrated it with a satellite back haul,” Herndon recounted.¹³

One of the first deployments, due to a request of the Department of Justice’s Office of Defense Preparedness, was to Salt Lake City for the 2002 Winter Olympics where organizers expected a flow of 70,000 visitors each day. “InfraLynx provided closed circuit TV surveillance and a land-mobile communications bridge from Park City, over the mountain, back down to Salt Lake City to FEMA’s command center,” Herndon said. If all other communication infrastructure went down, this truck could just about replace it, at least on a stopgap basis. The vehicle also was equipped to

provide two-way links through commercial satellites, data networking (including the ability to handle streaming video), and land-based mobile radio service. It also could serve as a private cellular telephone switching station.

InfraLynx teams would be called to service over the next years for a variety of national needs. The mobile C4I truck that the NCST outfitted became the model for dozens more vehicles that would go into service for various federal agencies.¹⁴ “Basically all of these vehicles are designed around the idea that they have interchangeable components that we can rack and stack depending on what your requirements are and what the task is,” said Morgan.¹⁵

One of Morgan’s more memorable deployments was to Navy-heavy San Diego in 2003 for Super Bowl XXXVII in which the Tampa Bay Buccaneers defeated the Oakland Raiders, 48–21, in front of 67,603 fans. The 9/11 attacks occurred only 14 months earlier and any large gathering with iconic Western symbolism was considered a prime target for another Al Qaeda attack. Among the more than 4,000 law and security officers and staff at the event, NCST deployed a Humvee-based InfraLynx vehicle and a crew, including Morgan, to San Diego. “The threat at the Super Bowl was that Qualcomm Stadium was a seven-minute flight from an airport in Mexico,” Morgan noted, adding that there also was a fuel refinery nearby. Some distance away from the stadium itself, he said, “we were set up in a location to give restorative communications links if an event occurred.” Fortunately, no such event occurred.

The NCST engineers did not get to watch the game in the stadium, but they were treated to some perks. “The San Diego Police Department was so tickled to have the capability out there that they took my entire team to the ‘NFL Experience’ the night before the Super Bowl so they got to meet the players,” Herndon said.¹⁶

Another big year for InfraLynx was 2005. NCST teams deployed to New Orleans and Texas to help make up for the pivotal communications systems taken down in the one-two punch of Hurricane Katrina, which devastated New Orleans and other parts of the Gulf Coast, and Hurricane Rita, which bore down especially on the Louisiana/Texas border. The seed of the deployment was planted when Roberts received a call on Saturday morning (during his son’s soccer game) from a “gentleman with CNI,” which stands for Commander of Navy Installations, who told Roberts he had heard that NRL had mobile communications ability. That set a series of actions into motion. As Roberts began seeking authority to get the InfraLynx truck and a support truck rolling south from NRL, Morgan and several colleagues were prepping the vehicles and testing their systems. By Tuesday morning, NRL’s Director of Research, John Montgomery, gave the green light and two NCST trucks headed to devastated New Orleans.

“We got in the vehicle [at NRL], we drove down to New Orleans, we set up, and we got our [initial] marching orders from the local command,” Roberts said. The NCST team parked the truck on a street outside the city’s convention center.¹⁷ The truck effectively became a major wireless communications conduit that replaced

some of the region's lost landline infrastructure. "We wired the Convention Center's communication system basically into our vehicle so that we could back haul it over a satellite," said Roberts. The team members, usually six at a time, slept on the floors of the two trucks NCST had deployed.

"We established a satellite link back here in DC," by way of a receiving antenna on top of NRL's Building 12, Morgan explained. Colleagues in NRL's Systems Directorate had a receiving antenna there that could pick up InfraLynx signals. "And once we connected back here, we could put out a variety of communications capabilities to a ground site back in New Orleans or a command post."¹⁸ The NCST hub served as a stopgap until USS *Iwo Jima*, an amphibious assault ship nearly three football fields long, arrived with its own high-volume satellite communications abilities. By that time, even commercial carriers, like Verizon and ATT, also had been able to reestablish some communications lines.

Once USS *Iwo Jima* and its crew arrived, Roberts noted, "they pretty much took over and we were no longer needed."¹⁹ This was a sure sign that the InfraLynx technology had done the job its NRL designers envisioned it could do. It was just then, though, that Hurricane Rita came barreling in and CNI asked Roberts to redeploy the InfraLynx team for that impending disaster. So Morgan and his colleagues set up shop in Jasper, Texas, and provided communications service for about 10 days to Jasper County's Emergency Operations Center. After that, the NRLers finally were able to return home. All in all, Morgan said, he was away from the lab for two months or so, and upwards of 20 NCST staff rotated in and out during that time.

The promise of the InfraLynx system was becoming known among government communications agencies well before it had proved itself in that terrible 2005 hurricane season. Very soon after the 9/11 attacks, recalled Herndon, "I got a call one day and was asked to come over to the Anacostia Naval Station" to the White House Communications Agency (WHCA), just a mile or so north of NRL on the other side of Bolling Air Force Base. Said Herndon, "I met with a Colonel and some other folks and we talked about communications issues."²⁰ It was a sure sign that word about InfraLynx was getting around. Herndon was asked to draw upon NCST's deep experience and track record with C4I technologies to help the WHCA strengthen White House communications abilities on the road. "I was sucked into the White House Communications Agency at that point," Herndon said, clearly happy that he had been.

"That sparked a relationship with us and we designed over the next four years nine different development projects for various communications systems," Roberts recalled.²¹ This work all unfolded during the administration of President George W. Bush, but the relationship never ended. Roberts pointed out that all versions of these mobile communications hubs evolved from the A2C2S project during the 1990s and included spinoffs of the Joint Combat Information Terminal (JCIT).

NRL's C4ISR experts and WHCA developed a long-term relationship that has continued. Herndon credits Jerry Phillips, his former boss when they were both

working on MATT, IDM, and other C4I components in the 1990s, with teaching him how to promote technological know-how and hardware to government partners like the WHCA.²² In Presidential motorcades, a hint of NCST's handiwork is visible atop a heavily modified Chevrolet Suburban known as the Mobile Communications Vehicle (MCV). The MCV is a rolling platform to provide communications for the President at times when he is not at the White House.²³ "While we are not providing the WHCA as much as we used to, we still provide critical comms to the President's cars and motorcades and provide other support to the agency in areas such as technical consulting," said Andy Cox, a longtime leader in NRL's C4ISR work. "We are the ones who are responsible for the technology in these vehicles."²⁴

The Air Force Space Command, the organization responsible for, among other things, maintaining the nation's intercontinental ballistic missiles in remote locations, was another high-priority InfraLynx customer. "The ICBMs get moved out of the silos and get transferred [by truck] to an upper level maintenance facility and then get pulled back down" into their silos, Roberts explained. "So there is swapping. Every so often the transport trucks, because of the high winds out west, were at risk of getting blown over," he notes nonchalantly. "So then you have an incident and of course you have a nuclear weapon on a truck. So what they need in that sort of circumstance is a mobile command post. They came to us for that. So we developed a mobile command post."²⁵ Roberts stressed that all of this sounds worse than it is because the weapons are built to withstand this sort of rare incident.

"We built three trucks," dubbed Minuteman InfraLynx Communications Systems (MICS), said Cox.²⁶ These are full-service communications hubs, featuring voice over internet, data, video, and other communications formats, all with satellite linkage anywhere, anytime. The NRL team delivered the trucks to three Air Force bases in the late 2000s: Malmstrom AFB in Montana, Minot AFB in North Dakota, and F.E. Warren AFB in Cheyenne, Wyoming.

All in all, Roberts estimates that the NCST InfraLynx team prepared about 50 customized communications vehicles. Now, much of this technology has transferred to commercial companies with which government agencies can contract for production models.²⁷ Meanwhile, the same body of work that NCST has been doing and the same portfolio of technologies it has been developing has kept on catalyzing new collaborations.

One of these has been with the Maryland Natural Resources Police (NRP), the enforcement arm of the state's Department of Natural Resources (DNR). Following the 9/11 attacks, the charge of helping to protect the country from acts of terrorism that might come in by way of Maryland waters became more prominent for the NRP. "When Osama bin Laden was killed, intelligence gathered from his compound suggested there could be threats against commercial rail travel, so the Governor of Maryland told his security guys that he wanted coverage for railroad bridges that go

over Maryland waterways,” Roberts said.²⁸ “We assisted Maryland’s anti-terrorism mission from the water with a real-time vessel tracking system.”²⁹

It took some time for the collaboration to build momentum, but in 2010 the NRL/NRP team began assembling what would become the Maritime Law Enforcement Information Network (MLEIN) with roles ranging from homeland security to conservation law enforcement to search and rescue missions. By the end of fiscal year 2014, the team had set up 10 fixed radar towers for monitoring, tracking, and identifying vessels in the northern part of the Chesapeake Bay and beyond to the Atlantic Ocean near Ocean City, Maryland, and into the National Capital Region, which includes the District of Columbia and six near-in counties in Maryland and Virginia. These look like communications towers except that they have radar antennas and cameras mounted on them. The team augmented this surveillance network with a transportable sensor system that can operate in areas where communications and power infrastructures are lacking. In addition, in 2012 and 2013, Roberts and his NCST colleagues fitted 30 vessels of the multi-agency Maritime Tactical Operations Group (MTOG) with antennas, transponders, and other equipment that collectively formed into a secure tracking system linked into a command center from which it is possible to monitor, manage, integrate, and deploy all of the MLEIN’s resources.

In 2013, the NRP began reporting using the new NCST-developed vessel-tracking and surveillance system to thwart illegal fishing and poaching in oyster beds and to identify and assist boaters in distress. “With its ability to be on duty around the clock and to see for miles, no matter what the weather, MLEIN makes the Bay and its tributaries a smaller neighborhood to patrol,” said NRP Superintendent Colonel George F. Johnson IV in a statement released by the NRP in late 2013.³⁰

These particular applications are a far cry from anti-terrorism roles but they still are part of NRP’s law enforcement responsibilities. They are an even farther cry from the Space Age origins of NCST, yet there is a discernible line from NRL’s early satellite work to its extension into maritime and terrestrial surveillance, military C4ISR, and onward into law enforcement initiatives against oyster poaching in the Chesapeake Bay.

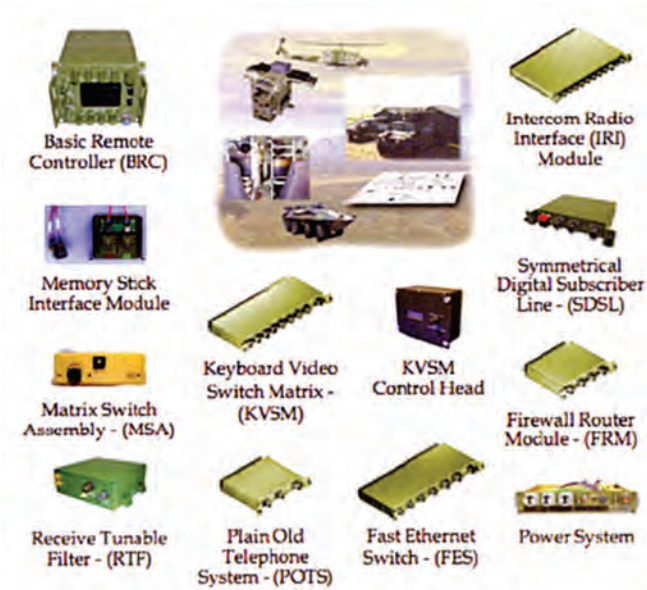
As NCST’s C4I engineers and their industry partners developed TRE, MATT, IDM, JCIT, and variations on these themes for tactical information systems that could package and deliver data from satellites and other intelligence-gathering assets, upper echelon military planners were craving ever more agility in these systems. NCST’s own long-term emphasis on eking as much tactical value for warfighters out of the large and small components of the national intelligence infrastructure was complemented and supplemented by such strategic-level conceptual frameworks as FORCEnet, which one seminal document defined as “the operational construct and architectural framework for naval warfare in the Information Age, integrating warriors, sensors, command and control, platforms, and weapons into a networked, distributed combat force.”³¹

Just as the TENCAP mantra of getting “national capabilities”—even ones whose origins must remain highly classified—into the hands of warfighters for tactical guidance required interfaces such as MATT, so too would the Navy’s call for expanding this trend to net-readiness. This could only be achieved with interface technology between the existing Internet infrastructure and specific Navy systems—whether it is a SIGINT satellite or Tactical Receive Equipment on one of the Navy’s several hundred ships. So the plan for naval forces to become more net-centric included funding for an all-purpose, net-ready, C4ISR interface. Funded by and primarily for the Marine Corps and called the Universal Communication Interface Module, or UCIM, the device had to work both with newer net-ready equipment and with older legacy systems. To integrate the latter systems, their outputs would have to be converted into net-friendly forms. And input to them from the net would have to be converted into forms the legacy systems could manage. It was akin to the way NCST’s Software Defined Radio technology could work both with legacy radio systems already bought and installed in thousands of air, ground, and floating vehicles, and with new and future communications systems.

“Basically, the UCIM takes everything in a Tactical Operations Center [TOC] and it allows you to integrate it all into a single,” far more mobile platform, remarked Bob Eisenhauer, who was central in NCST adopting the development of tactical communication equipment as a major part of its portfolio.³² “UCIM enabled you to go into an existing TOC and replace all the point-to-point connections between computers and radios with a digital backbone that allowed any device to communicate with any other without having to be wired to each other directly,” added Art Collier, the former head of the Special Projects Office and who has been a keen observer of NCST over the years. “This included new digital equipment as well as old analog ones.”³³

This spurred Eisenhauer and his NCST colleagues, along with industry partners, to mix and match all of the boxes that emerged during the C4I-related technology development since the 1980s into assemblages tailored for specific platforms. These include ones for the modified Chevrolet Suburbans in the President’s motorcade, for fast-moving military field operations, such as TOCs, and for temporary communications outposts during disasters like Hurricanes Katrina, Rita, and Sandy.

The Secretary of Defense also was seeking to exploit with more agility the ever more detailed situational awareness that the vast C4ISR system of systems was providing. Toward that end, in May 2003, the Secretary of Defense’s Office of Force Transformation launched the Operationally Responsive Space (ORS) program.³⁴ NRL joined this effort by developing components for a tactical space system concept that would give the Department of Defense an ability to quickly place equipment-bearing platforms into low Earth orbit for specific tactical and intelligence, surveillance, and reconnaissance needs in a particular situation, say, a sudden outbreak of hostilities in mountainous terrain like the Tora Bora region on the Afghanistan-Pakistan border. A series of tactical satellites, or TacSats, became the focus of NCST’s latest generation



Platform Integration Packaging



Radio Rack



Enclave Rack

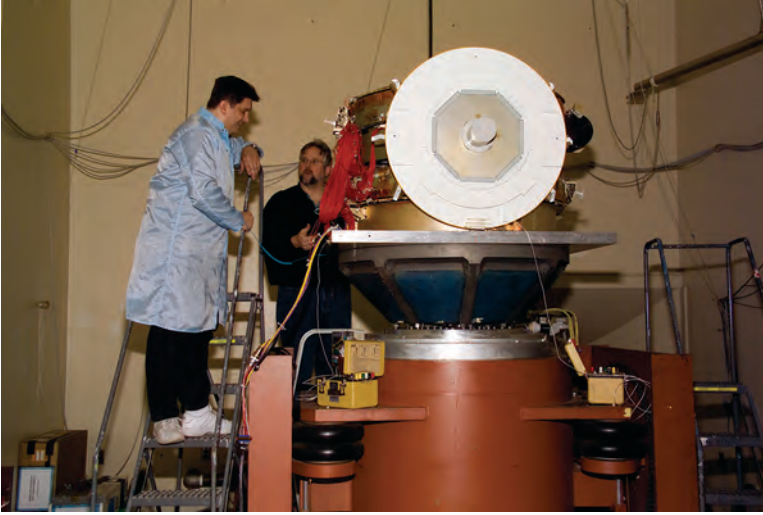


Radio/Computer Rack

Black Boxes. The Universal Communication Interface Module, which is a module of mix-and-match modules, addresses the need to interlink an enormous diversity of communications, data processing, computers, and other devices to the Internet and defense communications infrastructures.

of satellite engineers. With ORS, NCST was getting back in the game of building satellites, albeit on a smaller scale than when it was routinely building satellites for NRO and SDIO.

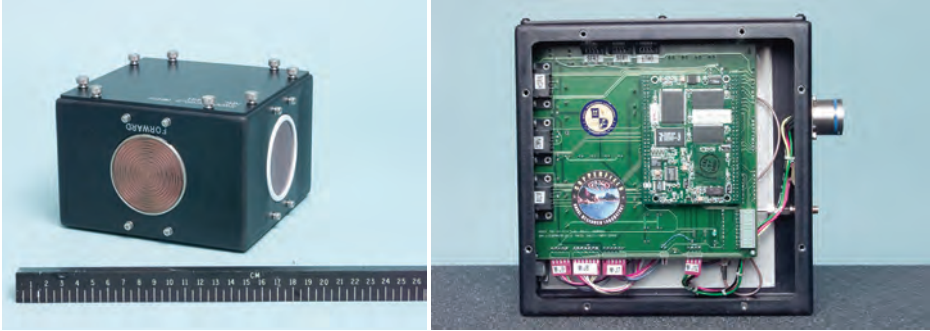
The first of this series, TacSat-1, proved to be a dry run of sorts in that the spacecraft was built in Building A59—from mid-2003 to mid-2004—but never launched. The point of the ORS mission was to demonstrate that within a year of a request and a green light by those with authority to give it, an operational satellite with ELINT, ocean surveillance, and/or other tactically valuable capabilities could be placed into orbit with a commercial launch vehicle and at a modest expenditure compared to that of traditional space missions. For the TacSat-1 mission, “the entire spacecraft was completed in less than a year, from go-ahead to the end of system-level testing, for less than \$10M,” according to Timothy M. Duffey and Michael S. Hurley, Jr., the principal NCST engineers on the project.³⁵



Space Comms. TacSat-1 was designed as the first of what would become a series of payloads designed to improve tactical communications for operational warfighters in mountainous, canyon-rich, and other communications-difficult regions. TacSat-1, shown here in 2004 undergoing preparations, was not launched but its follow-on payloads were. (NRL photo DG7P1080.jpg)

TacSat-1 was slated for launch in 2004 from Omelek Island (in the Kwajalein Atoll in the Pacific Ocean) in what would have been a spectacular and historic space technology demonstration for the nascent commercial space industry: it would have been the maiden voyage and mission for the Falcon 1, which space entrepreneur Elon Musk's firm SpaceX (Space Exploration Technologies) had designed and built.

The flight was scrubbed in part, however, when it became clear that the second in the series, TacSat-2, could host an advanced sensor for tracking ships (via the Automatic Identification System) in a smaller, lighter, and less power-hungry package. The NRL payload on TacSat-2 was known as the Target Indicator Experiment, or TIE.³⁶ Had the SpaceX rocket become qualified for the launch sooner, noted NCST engineer Chris Huffine (an expert in software reprogrammable radio and signals collection technologies), the payload might have made it into orbit before a new generation of technology came around. The shelving of TacSat-1 for a more capable TacSat-2 also bought enough time to include an NCST-developed tactical sensor and computer system known as Copperfield-2 for the comprehensive task of keeping track of as much ocean traffic as possible. There was just so much more that TacSat-2 could demonstrate that it no longer seemed prudent to the sponsor (the Operationally Responsive Space Office) and the NCST team to spend the \$5 million or so that it would cost to actually launch TacSat-1. It was a novel decision dynamic that resided in the deliberately rapid development time of these satellites designed within the ORS framework. As a result, just like the Interim Control Module (ICM) that NCST engineers had built and readied in case the Russians didn't come through with a booster unit for the International Space Station, TacSat-1 joined the ranks of the good-to-go but unlaunched satellites.



Copperfield. Designed for airborne platforms involved in tracking maritime traffic, engineers at the Naval Center for Space Technology designed a miniaturized electronic intelligence system known as Copperfield, shown here in two views. (NRL photos B58Z6804.tif and B58Z6813.tif)

On December 16, 2006, just seven months after the initiation of the contract for the TacSat-2 mission, a Minotaur 1 booster, designed and supplied by Orbital Sciences, headquartered near Dulles Airport in Virginia, lifted TacSat-2 from Wallops Island Space Flight Facility in Virginia to a low Earth orbit of about 260 miles (420 kilometers). This was an Air Force-led mission that included another 10 or so scientific and experimental technology payloads beyond NCST's TIE payload. Its roughly 40-degree inclination established an orbit that provided simultaneous coverage of a circular surface domain about 2,500 miles (4,000 kilometers) in diameter as the spacecraft flew over the Earth. The global ocean surveillance framework known as maritime domain awareness had begun.³⁷



TacSat-2. NCST engineers integrate antennas—including ones that will tap into the maritime system known as AIS, or Automatic Identification System—onto the TacSat-2 spacecraft in preparation for a launch in December 2006.

NCST was not involved in TacSat-3, another Air Force-led mission run out of the Air Force Research Laboratory's Space Vehicles Directorate at Kirtland Air Force Base in Albuquerque, New Mexico. That satellite was launched with a Minotaur 1 booster on May 19, 2009. According to an Air Force press release issued on May 1, 2012, the day the satellite burned up during reentry, "TacSat-3 was the first on-orbit Department of Defense intelligence, surveillance and reconnaissance capability delivered to U.S. Strategic Command for their direct imagery support to worldwide combatant commanders."³⁸

A half-year before TacSat-3 de-orbited, TacSat-4, this one an NCST-led mission with some 30 key personnel involved, made it into orbit after a spectacular nighttime launch on September 27, 2011 with a Minotaur IV+ booster from the Kodiak Launch Complex in Alaska, which is run by the Alaska Aerospace Corporation. The Operationally Responsive Space Office funded the launch.³⁹ The original launch date had been set for two years earlier, but that date changed due to delays associated with the booster, as well as Department of Defense-specified changes in the mission's requirements.⁴⁰ As had been the case so many times before, an NCST team at the lab's Blossom Point Tracking Facility in southern Maryland monitored and controlled the spacecraft throughout its service lifetime.



TacSat-4. On September 27, 2011, at the Kodiak Launch Complex in Alaska, a Minotaur IV+ booster begins to ferry TacSat-4 into orbit where the spacecraft tested out tactical communication roles for a variety of end users. (Source: U.S. Navy photo by John F. Williams)

Still in orbit as of 2014 but lacking funding for what had been a possible transition from an experimental to operational satellite,⁴¹ the spacecraft's primary function was to push forward ultra-high-frequency (UHF) satellite communication technologies using UHF channels suitable for tactical communication; data transfer; and "friendly force tracking" to help global surveillance systems better distinguish between friendly and hostile military assets. The radio communication system was designed particularly to support forces on the move so that even individual warfighters with "manpack" tactical receive radios could readily and quickly tap into TacSat-4 signals in ways that minimize their exposure to enemy gunfire and hostility.

The spacecraft's highly elliptical orbit placed it routinely in a high-perch position where it offered lines of sight into otherwise hard-to-reach battle regions such as the valleys and crevices in mountainous settings including those in Afghanistan and Pakistan. These hotbed regions are not routinely serviceable using the higher-flying geosynchronous spacecraft that remain affixed above a particular equatorial surface spot of the planet.

The TacSat-4 mission also pushed forward the strategy for designing and building a standard satellite bus, that is, a common physical framework onto which many kinds of components can be integrated in an essentially plug-and-play manner. The notion is that with such standardization will come improved reliability and agility for

quick-turnaround satellites. That, in turn, should reduce costs for future tactical satellites, automated ground operations, net-centric operations, and other elements of the Operationally Responsive Space concept. The mission's so-called Integrated Systems Engineering Team (ISET) included a dozen government and industry partners. NRL and the Johns Hopkins University's Applied Physics Laboratory designed and built the "ORS Phase III Standardized Bus."⁴²

For NCST, TacSat-4, which is no longer functioning but whose payload and first year of operation was funded by the Office of Naval Research, was a milestone simply by virtue of making it into space, let alone for the technologies it carried there; TacSat-4 stood as NRL's 100th acknowledged satellite. In the summer of 2012, TacSat-4 was an important part of the annual weeks-long Trident Warrior exercise during which the Navy tested experimental tactics, techniques, and technologies to see if and how to continue developing them for the fleet.⁴³ The tests with TacSat-4 proved, among other things, that a quick-response, low-cost space platform could link ship and submarine warfighters with both mobile and stationary ground-based units. In a smaller test earlier in 2012, the U.S. Coast Guard Cutter *Healy* (WAGB 20) used TacSat-4 to communicate from its location in the Bering Sea off the western coast of Alaska to the U.S. Coast Guard Base in Alameda, California.⁴⁴

Among the other end users putting TacSat-4 to the test were the U.S. Army's Space and Missile Defense Command Battle Laboratory, the U.S. Marine Corps, and international partners in the United Kingdom and Canada. Among the experiments the end users performed were ones that used TacSat-4 with various legacy radios and antenna types to determine the best combinations; ones that evaluated the orbiting link in mountainous and urban settings by users who are on foot or in moving vehicles; ones that tested the spacecraft in time-sensitive tasks, such as an uplink and relay for "unattended ground sensors"; and to flight-test a new lithium ion cell battery design.⁴⁵

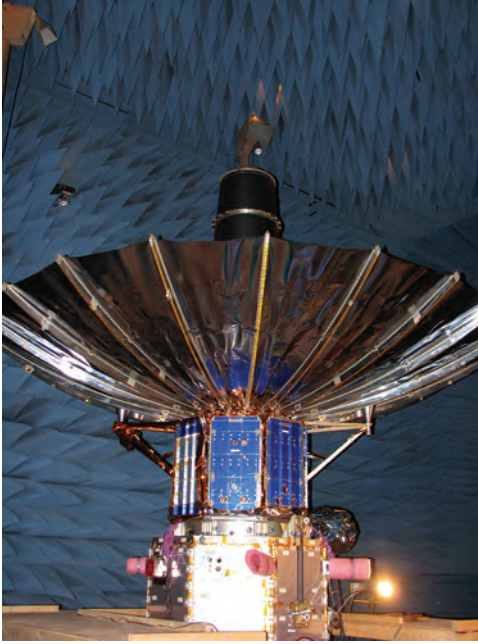
TacSat-4 might never have made it to the launchpad were it not for a young mechanical engineer, Christopher Amend, whom NCST hired into its Spacecraft Engineering Department from Virginia Polytechnic Institute and State University in Blacksburg. One of his early assignments was to work with some colleagues, including RF (radio frequency) engineer Michael Nurnberger, to procure a deployable antenna with the right characteristics for TacSat-4's mission and expected capabilities. "So they put out an RFP" that is, a Request for Proposals, from companies who could bid on the job, recounted John Schaub, a longtime head of NCST's Spacecraft Engineering Department (SED) and director of NCST from 2016 to 2018. "The proposals they got back were for dollar amounts that exceeded the budget we had for the entire program."⁴⁶ And that was just for the reflector, not the entire antenna system. "So we said to Chris, 'Why don't you come up with a design?' And he didn't know any better, so he came up with an antenna for about one tenth the cost," Schaub said with a smile on this face.



Team TacSat. The TacSat-4 satellite, shown here in 2010 in Building A59 with the team that built COMMx, the major component of the spacecraft aside from its overall framework, or bus. Still furled, the umbrella-like antenna (large, silver-colored component above the blue bus) embodies innovations that kept overall costs manageable. A larger TacSat team in early 2011 prepared the spacecraft for shipping—by way of an Air Force C-17 and a truck—to the Alaska Aerospace Kodiak Launch Complex. There, in September 2011, an Orbital Sciences Minotaur IV+ booster launched TacSat-4 into a highly elliptical orbit (HEO) with an apogee of 12,050 kilometers. (NRL photos 100823-N-3456S-025.jpg and 110224-N-4822H-118.jpg)

It was a feat of design and engineering for which Amend and Nurnberger secured a patent. The mission required that the 12-foot-diameter reflector, once it unfolded and was deployed in space, deviated from a perfect parabolic shape by no more than a quarter of an inch. This was a tight tolerance but actually forgiving enough to open cost-effective options to the NCST design team. In addition, the antenna could weigh no more than 60 pounds and had to be delivered within a year for a cost under \$4 million, all of which forced the decision to design and build the antenna in NCST's own Building A59. Amend, Nurnberger, and their colleagues needed to determine

the best folding geometry and mechanism for unfurling the antenna. They needed to make materials choices for the framework, ribs, springs, and components of the umbrella-like structure, all the while remaining within weight specifications. Also a key driver of the design was to minimize any metal-to-metal contacts, which models and simulations indicated could reduce the antenna's all-important reception sensitivity.



Space Umbrella. Shown in all of its unfurled glory is the umbrella-like main receiving antenna of TacSat-4 as it undergoes radio frequency testing in an anechoic chamber at NRL. (NRL photo IMG_4655.JPG)

The team zeroed in on a design in which they would use 2,000 nonmetallic but high-performance fasteners to link triangular-shaped panels (gores) both to each other and to the ribs of the deployment structure using a high-tech polymer called Kapton. The team even made sure the reflector membrane was of a precise thickness so that the gores would behave as RF reflectors, rather than absorbers or scatterers of specific ranges of RF signals. There were 1,001 additional details and problems to overcome. And it all had to be light enough and tough enough to make it into orbit and work once it got there. Three days after the TacSat-4 launch, the NCST-designed receiver antenna popped open like an umbrella, and a few days after that began relaying voice messages.⁴⁷

NCST's TacSat-4 team, under Program Manager William (Bill) Raynor and mission design principal investigator Michael Hurley, built the spacecraft, solving countless challenges all along the way, just as had been done at NRL since the Vanguard era. Designed with cost, versatility, and the ability for quick concept-to-launch turnaround in mind, the project always has been modest compared to the Department of Defense's next-generation communication satellite system known as Mobile User Objective System (MUOS). That system, slated for completion later in the decade, by

which time all four of the system's massive geosynchronous satellites are scheduled to be in place, will amount to a worldwide substitute for cell-phone towers for military users in need of voice or data connections anywhere, anytime.

According to Raynor, Hurley, and the ORS launch sponsor, TacSat-4 (during its experimental lifetime, which effectively ended with the close of 2013) "demonstrated SATCOM performance that matches or beats current geosynchronous satellites" for some voice and signal communications capabilities while also "demonstrating many elements of the ORS concept such as maturing the ORS bus standards, developing an enhanced Minotaur-IV+ launch vehicle capability ... and highly automated command and control." As TacSat-4's leadership sees it, a constellation of six TacSat-4-like satellites could provide nearly continuous communications coverage for any possible theater of war. For now, the single experimental TacSat-4 remains on-orbit but is not funded for a transition to an operational status. "Follow-on efforts have been studied and should the need arise, a TacSat-4-like constellation could be procured and provide utility to any number of users," Raynor and Hurley said in 2013 at a conference of fellow experts who are pushing the boundaries of small satellite design and operation.⁴⁸

¹ Maryann Lawlor, "Keeping the President Connected," *Signal* (online), September 2004, <http://www.afcea.org/content/?q=node/346>.

² Robert Roberts, interview with author in the presence of George Arthur and Bruce Morgan, April 19, 2012.

³ George Arthur, interview with author in the presence of Robert Roberts and Bruce Morgan, April 19, 2012.

⁴ David Derieux, interview with author on September 9, 2012. In the 1980s, David Derieux worked for a summer at NRL alongside his father, Thomas Derieux, who was part of the team working with the high powered Pharos laser as part of the lab's plasma physics program (for fission and fusion studies).

⁵ George Arthur, interview, 2012.

⁶ NRL Press Release, August 26, 2104, "New York City Tracks Firefighters to Scene with NRL Radio Tags, Automated Display," <http://www.nrl.navy.mil/media/news-releases/2014/new-york-city-tracks-firefighters-to-scene-with-nrl-radio-tags-automated-display#sthash.QsDgjJuw.dpuf>.

⁷ George Arthur, interview, 2012.

⁸ Bruce Morgan, interview with author in the presence of Robert Roberts and George Arthur, April 19, 2012.

⁹ Chris Herndon, interview with author, February 4, 2013.

¹⁰ Chris Herndon, interview, 2013; also see Naval Research Laboratory, "The U.S. Naval Research Laboratory (1923–2005) Fulfilling the Roosevelts' Vision for American Naval Power," NRL/MR/1001--06-8951 (Washington, DC: Naval Research Laboratory, March 6, 2006), p. 62.

¹¹ Chris Herndon, interview, 2013.

¹² *Science Daily*, February 11, 2002, accessed at <http://www.sciencedaily.com/releases/2002/02/020211080250.htm>.

¹³ Chris Herndon, interview, 2013.

¹⁴ Robert Roberts, interview, 2012.

¹⁵ Bruce Morgan, interview, 2012.

- ¹⁶ Chris Herndon, interview, 2013.
- ¹⁷ Robert Roberts, interview, 2012.
- ¹⁸ Bruce Morgan, interview, 2012.
- ¹⁹ Robert Roberts, interview, 2012.
- ²⁰ Chris Herndon, interview, 2013.
- ²¹ Robert Roberts, interview, 2012.
- ²² Chris Herndon, interview, 2013.
- ²³ Chris Herndon, interview, 2013.
- ²⁴ Andy Cox, personal communication, March 2014.
- ²⁵ Robert Roberts, interview, 2012.
- ²⁶ Andy Cox, personal communication, March 2014.
- ²⁷ Robert Roberts, interview, 2012.
- ²⁸ Robert Roberts, interview, 2012.
- ²⁹ Draft of “Maritime Law Enforcement Information Network (MLIEN),” an item submitted by NCST Section 4130 to NRL leadership as a FY14 R&D Accomplishment; “Encrypted Tracking System (ETS) Integration for Maryland Natural Resources Police (NRP) and the Maritime Tactical Operations Group (MTOG),” NRL/PU/8140--13-586, October 2013, Naval Research Laboratory, Washington, DC.
- ³⁰ <http://news.maryland.gov/dnr/2013/11/06/new-nrp-enforcement-tool-reaps-early-rewards/>.
- ³¹ Vern Clark, Admiral USN, Chief of Naval Operations, Michael W. Hagee, General USMC, Commandant of the Marine Corps, 2005, “FORCENet A Functional Concept for the 21st Century,” accessed at <http://www.navy.mil/navydata/policy/forcenet/forcenet21.pdf>.
- ³² Robert Eisenhauer, interview with author and Art Collier, March 12, 2012.
- ³³ Art Collier, personal correspondence.
- ³⁴ See the Operationally Responsive Space web site: <http://ors.csd.disa.mil/>.
- ³⁵ *2005 NRL Review* (Washington, DC: Naval Research Laboratory, 2005), pp. 227–229.
- ³⁶ Chris Huffine, “TacSat-2, Target Indicator Experiment (TIE), AIS Payload Overview,” presented at 2007 Maritime Domain Awareness Forum, dated October 27, 2007.
- ³⁷ Chris Huffine, interview with author, March 12, 2012.
- ³⁸ Air Force Space Command press release, “TacSat-3 Ends Operations,” May 1, 2012, <http://www.afspc.af.mil/news/story.asp?id=123300195>.
- ³⁹ Naval Research Laboratory, “TacSat-4 Lifts Off... Augmenting SATCOM and Advancing Operationally Responsive Space,” *Spectra* (Washington, DC: Naval Research Laboratory, Fall 2011), pp. 1–5.
- ⁴⁰ eoPortal, “TacSat-4,” <https://directory.eoportal.org/web/eoportal/satellite-missions/t/tac-sat-4#gp8EC19cHerb>.
- ⁴¹ Matthew Anderson, Bill Raynor, and Mike Hurley, “TacSat-4: Military Utility in Small Communications Package,” presented at the 27th Annual AIAA/USU Conference on Small Satellites, August 10–15, 2013, University of Utah in Logan.
- ⁴² The “ISET Team” included AeroAstro, Air Force Research Laboratory, Johns Hopkins University APL, ATK Space, Ball Aerospace & Technologies, Boeing, Design Net Engineering, General Dynamics AIS, Microcosm, Sierra Nevada Corp., Massachusetts Institute of Technology, Lincoln Laboratory, Orbital Sciences, NRL, SMC, Space Systems/Loral, and Raytheon.
- ⁴³ See, for example, NRL Press Release, “TacSat-4 Participates in Navy Fleet Experiment Trident Warrior,” <http://www.nrl.navy.mil/media/news-releases/2012/tacsat-4-participates-in-navy-fleet-experiment-trident-warrior#sthash.MLfuIRjv.dpuf>.
- ⁴⁴ NRL Press Release, “TacSat-4 Enables Polar Region SatCom Experiment,” March 9, 2012, <http://www.nrl.navy.mil/media/news-releases/2012/tacsat-4-enables-polar-region-satcom-experiment>.
- ⁴⁵ eoPortal, “TacSat-4,” <https://directory.eoportal.org/web/eoportal/satellite-missions/t/tac-sat-4#gp8EC19cHerb>.
- ⁴⁶ John Schaub, interview with author, February 28, 2012.

⁴⁷ Chris Amend, Michael Nurnberger, Paul Oppenheimer, Steve Koss, and Bill Purdy, "A Novel Approach for a Low-Cost Deployable Antenna," NASA/CP-2010-216272, accessed at <http://www.esmats.eu/amspapers/pastpapers/pdfs/2010/amend.pdf>; see also <https://directory.eoportal.org/web/eoportal/satellite-missions/t/tacsat-4#gp8EC19cHerb>.

⁴⁸ Anderson et al., "TacSat-4: Military Utility in Small Communications Package," 2013.

NCST INSIDE

Starting with the Vanguard program and its first successfully launched satellite on St. Patrick's Day in 1958, the Naval Research Laboratory subsequently would place 100 satellites of one kind or another into orbit by the early years of the new millennium. TacSat-4, the 100th in this six-decade space venture, was boosted into orbit on September 27, 2011.¹ Any organization that has been responsible for, on average, at least one payload every year since the late 1950s has earned a prominent place in the emergence and evolution of the ongoing Space Age. But NRL's manifest of satellite and payload launches summarizes only the most visible chapters of the lab's overall space technology story.

"A lot happened that's not on that chart that was just part of a payload provided to someone, or that supported someone else's mission, and so is just lost between the pages of [NCST's] history," remarked mechanical engineer Aaron Chilbert of NCST's Spacecraft Engineering Department.²

Chilbert started working at NRL in 1983, before the lab's space technology efforts were consolidated and reorganized with the establishment of NCST in 1986. During his first few years, he said, the space technology program "was pretty well dominated by the NRO program and what was then the SDI program." At the time, NRL's part of the Strategic Defense Initiative's technical program centered on LACE and a classified NRO-sponsored program whose roots extend to the GRAB program in the early 1960s when NRO itself was first established. "These programs took us well into the early 1990s," Chilbert said,³ and overlapped for a decade with the expansion of NCST's C4I work that would be guided by the "sensor-to-shooter" technology ethic.

After that, he said, "the shift at the end of the Cold War, and congressionally directed reprioritization of funding, drove a lot of things in a different direction." Cost-cutting pressure, together with the earlier SDI connection, led to the NCST's central role in the budget-conscious Clementine technology-testing program that ended up yielding the finest map of the moon at the time.

"A lot of other smaller projects started coming up from various sponsors that we had never worked with before," noted Chilbert in his small office in the otherwise cavernous Building A59. One large category of work involved "radiation hardening" of sensitive electronic components for spacecraft. High-energy radiation, such as X-rays and cosmic rays, or fast moving electrons and other ions from solar storms—or even possibly from nuclear blasts in space—is what kills components and satellites in orbit and carries much of the blame for why spacecraft need to be replaced. "So there has

been a fair amount of work here just developing electronics that are tolerant to that environment,” said Chilbert.⁴

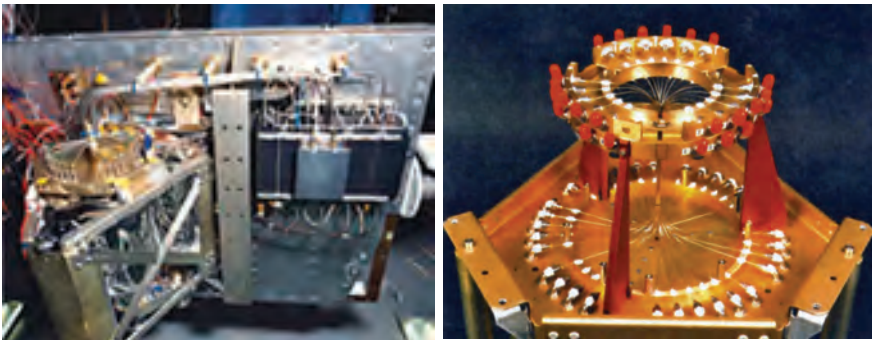
One low-profile example was the Microelectronics and Photonics Test Bed (MPTB), which carried 24 motherboards with various electronic and photonic devices into an elliptical orbital journey aboard a host satellite with the help of a Titan rocket in November 1997 for a multi-year space-environment-exposure experiment.⁵ In addition to directly measuring how space radiation affects the performance of microelectronic and photonic devices, the payload simultaneously measured and characterized the on-orbit radiation environment. A complementary component of the mission was to conduct extensive ground tests in which the same devices that were flown in space were subjected in laboratory settings to radioactive sources, such as radioactive isotopes and beams from particle accelerators. This enabled the MPTB team to evaluate how well the simpler and less costly ground-based experiments reflect what actually happens in space. For this project, NCST engineers worked with NRL partners in the Solid State Devices Branch of the lab's Electronics Science and Technology Division.

“It was just one of those 1990s kinds of programs to take COTS [commercial off-the-shelf] hardware and prove it can work in the space environment,” Chilbert noted, referring to a government-wide push to avoid reinventing wheels, as it were, if suitable technologies had already been developed and were available in the commercial sector. “It was a collection of a lot of little experiments from many different providers—universities, international partners, all sorts of partners. And NRL—this group at NCST—pulled it all together on a payload.”⁶ The lessons learned during the MPTB project about how components fail in space due to radiation effects, and about which radiation-hardening tactics are more protective than others, were transferred to the partners on the project. By way of example, Chilbert noted that the company BAE Systems, which was working on reconfigurable logic circuits known as field programmable gate arrays (FPGAs), was able to make these devices more space-worthy due to data from the MPTB.

The High-Temperature Superconductivity Space Experiment (HTSSE) was another consequential space technology program that represents the way the lab routinely assembles the multiple skill sets it has on hand to pull off complex, high-risk experiments that expand the boundaries of what is possible in space. HTSSE's roots began just as the Naval Center for Space Technology was established in 1986. That same year, materials researchers with IBM reported their discovery of remarkable materials that could conduct electricity without any resistance whatsoever at temperatures much higher than could any previously known superconductors. The discovery of these new materials, dubbed high temperature superconductors (HTSCs), set off a global research wildfire out of which quickly emerged several new families of HTSCs, including ones for which inexpensive liquid nitrogen cooling was sufficient to keep them superconductive. Over the next months, researchers around the world showed

that electronic and radio frequency devices made with these materials exhibited a combination of tantalizing properties, among them low noise (cleaner, clearer signals), low attenuation (stronger signals over longer distances), wide bandwidth (larger signal capacity), and high-speed switching (for high frequency communication, for example).

Within two years, engineers at NRL were taking bold steps to accelerate these laboratory developments toward HTSC devices that might improve the performance of space-based sensors and communications systems. In December 1988, NCST's Space Systems Development Department, along with partners in the lab's Materials Science and Technology Division, Condensed Matter and Radiation Sciences Division, and Electronics Science and Technology Division, initiated the HTSSE program with multiple sponsors, including the U.S. Navy, NRO, BMDO, and DARPA. The overall plan was for various academic, industry, and government HTSC research teams around the country, NRL among them, to submit designs for devices, such as receivers, analog-to-digital converters, and multiplexers, to NCST engineers. They, in turn, would help to render the devices space-worthy, rigorously test them, and integrate them into experimental payloads.



Chill Tech. It took innovative engineering to design and build a system capable of integrating almost a dozen experimental microwave devices that needed to be chilled with a liquid nitrogen cryogenic system. Shown is the overall system, known as the High Temperature Superconductivity Space Experiment (HTSSE), and a close-up of the components for circulating the chilled nitrogen. (NRL photos HTSSE 001 and HTSSE 002)

The first payload, HTSSE-I, would have carried a set of simple HTSC-based electronic devices into orbit had the U.S. Air Force satellite into which they were integrated not fallen into the ocean rather than making it into space. But even before that disappointment, NCST had begun work on HTSSE-II. Under the program leadership of Gerald Golba, the NCST team integrated eleven fully functional microwave components, which either were built in-house by partners in NRL's Materials Science and Technology Division or were delivered by external collaborators such as Westinghouse and TRW, into an innovative cryocooler-equipped framework designed under the leadership of NCST mechanical engineer Tom Kawecki.⁷ Kawecki, who joined the lab in 1982, had developed expertise in thermal design and cryogenic technology for

work he had done on a classified project. He was able to apply some of that know-how to the HTSSE-II-associated challenge of designing a cryocooler that could chill a dozen or so separate devices and subsystems to superconductivity-inducing temperatures. In an interview, he recalled the experience, fondly noting how Golba and the rest of NCST management provided him with an all-important “sense of ownership and responsibility.” He has an engineering model of the HTSSE payload in his office in Building A59 as a reminder of what it is all about for him and his NCST colleagues. “The reason we are engineers is that we like to build stuff,” he said.

The NCST HTSSE team—which included, among others, James Winkler, who worked on the complex “electrical harness” that had to accommodate all of the payload’s components, and old-timers Vince Rose and Ed Becke, who applied their expertise in integrating microwave devices into payloads⁸—then shipped the experiment-laden HTSSE payload to Rockwell International where it was integrated into the Advanced Research and Global Observation Satellite (ARGOS). On February 23, 1999, a Delta II booster hoisted ARGOS into orbit. And for the next three years, before the program was terminated, NCST satellite controllers at the lab’s Blossom Point facility controlled, monitored, and harvested data from the HTSSE devices. “This program was nationally touted for fostering industrial competitiveness in the area of superconducting microwave devices,” noted Donald Gubser, NRL’s lead materials scientist on the project.⁹

Observed Chilbert, “A lot of little projects like this have come and gone over the years.”¹⁰ And signs of them are all over Building A59 in both small and sometimes massive ways. Building A59, the largest structure on NRL’s main campus, is a physical embodiment of NRL’s long, bold, and ongoing role in the Space Age and the overall U.S. space program. The building’s initial mission in the 1940s, before it was annexed to become part of the Naval Research Laboratory, was to accommodate machinists and the massive naval and other military guns they were making or repairing throughout World War II. Remnants of that activity remain in the unimproved parts of the building in the form of rusting railroad tracks, pitted concrete loading bays, and steel-girded materials-moving frameworks fitted into the high ceilings. Juxtaposed with these open and often dank and dimly lit areas are building sectors that at various times over the years have been modernized into office suites, conference rooms, and high-tech laboratories, among them anechoic chambers for testing antenna performance and a clean room for working with semiconductor components. Some occupants of A59 describe it as a collection of smaller buildings within a larger building. Meander around A59 and you even can happen onto freight containers that were modified to serve as offices for, among others, Ed Becke, the brilliant RF technician who joined the lab in the 1940s, worked on classified and other programs (including the command, control, and data collection huts much like his own shipping-container office), and then continued on at NCST to exercise his expertise in antenna design until he died in 2013.

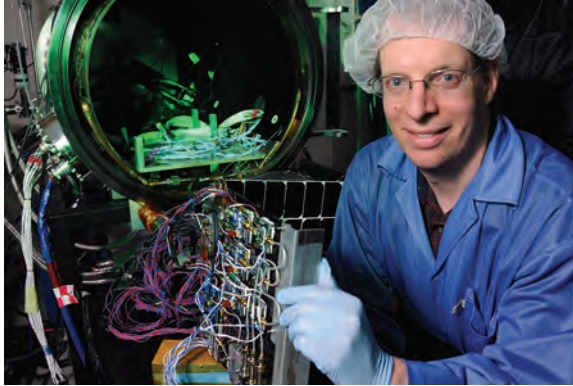
Besides the World War II-era spaces and the office areas are several enormous work spaces—high bays with ceilings that soar to 60 feet—where so much of NRL’s satellite building and testing has unfolded for decades. Throughout the building are electronics racks, multi-drawer cabinets, and other furnishings to hold everything from old and new oscilloscopes and RF waveguides, to wires and cables of any and all gauges, to memory chips and central processing units, along with ten thousand other components that space engineers know what to do with. Also in these high-bay areas are massive testing chambers, such as the 16-foot-diameter, 30-foot-deep “Big Blue,” which can host entire payloads and satellites and subject them to thermal and vacuum conditions similar to those in space, and a vibration chamber that can simulate the mechanical and acoustic rigors of a launch.

All over Building A59 are signs of workplace pride: pictures of satellite or payload teams who worked together night and day for months on end, framed photos of glorious launches at Cape Canaveral or Vandenberg Air Force Base, and large emblems commemorating the institutional teamwork that it takes to usher a space technology concept all the way into orbit. The same emblems, almost like family shields, end up on correspondence, shirt and jacket patches, and t-shirts and coffee mugs. Lumbering and unpretty as A59 might be, it is an embodiment of NRL’s and NCST’s history of accomplishment in space technology.

Chilbert’s NCST colleague Dr. Paul Jaffe, head of the Systems Integration Section of NCST’s Space Electronics Systems Development Branch, knows all about that accomplishment, at least since 1994. That’s when he was an electrical engineering student at the University of Maryland and in a co-op program in which he landed a junior engineer job in NRL’s Radar Division. It was a common school-to-work path way for many employees of NRL. Jaffe didn’t know it then, but within the next 20 years, his resume would include an ever-lengthening roster of spacecraft and space technology acronyms. “It was around the same time that Clementine was launched,” Jaffe recalled of his co-op days at NRL. “And they were doing the operations of the satellite and it was covered in Labstracts,” NRL’s campus newsletter. “I was like, ‘man, I would really like to work in that part of the lab.’”¹¹ Two years later, in 1996, that opportunity arose, but it would entail one of the most harrowing interviews Jaffe ever had. It was with George Flach, then head of the Space Electronics Systems Development Branch. Flach, an electronic engineer whose many roles would include chief engineer on the Interim Control Module project for the International Space Station,¹² had grown up professionally at NRL during the classified Poppy program in the 1960s. Said Jaffe: “There were a number of folks who interviewed me but I sweated more bullets during the interview with George than in all of the other interviews combined.”¹³

With a face that reveals little of his thinking and a deftness in the use of silence along with soft-spoken words to communicate, Flach, who continued after he retired to work for NCST as a consultant, could be intimidating. What made Jaffe sweat some

of those bullets was what followed when he told Flach that his hobby was to make little robots. “Hmm,” Jaffe recalled Flach saying, “so why don’t you draw me the control circuit for one that you built.” Jaffe stretched his memory and sketched out a circuit with Flach watching. “I was hoping I would not get the capacitor polarity wrong,” Jaffe said.¹⁴



Serial Engineer. Among the many projects engineer Dr. Paul Jaffe has worked on in the Naval Center for Space Technology is a module for converting solar radiation captured by photovoltaic panels into radio frequency energy that can be beamed to receivers. Jaffe is shown with the U-PRAM (Photovoltaic DC to RF Antenna Module) and a customized vacuum chamber for testing it in the background. (NRL photo 140128-N-JF840-007)

Jaffe’s first job as a new NCST engineer was to work on the Special Sensor Ultraviolet Limb Imager, or SSULI, which was a joint project with the lab’s Space Science Division. The denizens of this NRL division are the intellectual progeny of Dr. Herbert Friedman, Dr. Richard Tousey, and the NRL team of upper atmosphere researchers who got used to using rockets for their studies in the 1940s and 1950s and followed with the SOLRAD series of satellite payloads. In astronomy, the word “limb” refers to the edge of a disk of a celestial body, such as a planet, star, or moon. The SSULI project, which was aimed at improving the monitoring and forecasting of the behavior of the ionosphere, started back in the 1980s and was supposed to have been launched by the time Jaffe started at NRL. But as often is the case with space programs, the SSULI project did not unfold as expected.

The team was building a series of five imagers for use on the same number of satellites in the Defense Meteorological Satellite Program (DMSP). The Department of Defense had been relying on these satellites for generic weather monitoring and forecasting, but the SSULI instruments were designed to measure the effects of sun-driven space weather. “It detects things like the free electron concentration in the ionosphere and the prevalence of different ionic species, and from that you can answer questions like, ‘Will my over-the-horizon radar work on a given day and can you make a forecast model?’” Jaffe explained.¹⁵ The SSULI data also can help to predict and improve the accuracy of GPS, he added. By having the instrument viewing the planet’s limb at a glancing angle, it can get the clearest and most comprehensive view of the ionosphere

and capture data important for determining electron and ion concentrations. This first project of Jaffe's tied him back to the upper atmosphere and ionosphere research issues that were priorities for the lab's founding scientists who in the 1920s were trying to improve the Navy's high frequency communications abilities.

Rather than working on entire satellites to be delivered to a sponsor like NRO, SDIO/BMDO, or NASA, as was the case with programs like GRAB, Poppy, LACE, Clementine, and ICM, Jaffe's role was to work with a team on the SSULI, which was but one of many sensors that the DMSP satellites would carry. The first SSULI did not make it into its orbital perch until 2003, a good seven years after Jaffe began work on the project. By early 2014, four of the five remote sensing imagers he and his colleagues built had made it into orbit.¹⁶



Sensor Aloft. The contractor team of Lockheed Martin and United Launch Alliance orchestrated the launch of an Atlas V at 0746 on April 3, 2014, bearing the 19th Defense Meteorological Satellite Program payload and with it the fourth NRL-built SSULI sensor for measuring electron densities in the ionosphere.

Having learned the hard lesson after the GRAB and Poppy days of relying too much on a single sponsor, Jaffe's supervisors in NCST's Spacecraft Engineering Department soon had him splitting his time on other projects. "For any project, the politics could change and it could go away, or it could get canceled for any number of reasons," Jaffe pointed out in an interview.¹⁷ He provided as an example a project known as the Naval Earth Map Observer (NEMO). The mission, which was sponsored by the Office of Naval Research and several other Department of Defense entities, started out as a collaboration between government, primarily NRL, and industry partners, originally including Boeing and several smaller firms, including Space Technology Devel-

opment Corporation (STDC). The original agreement called for the government and the industry team to each pony up \$60 million.¹⁸

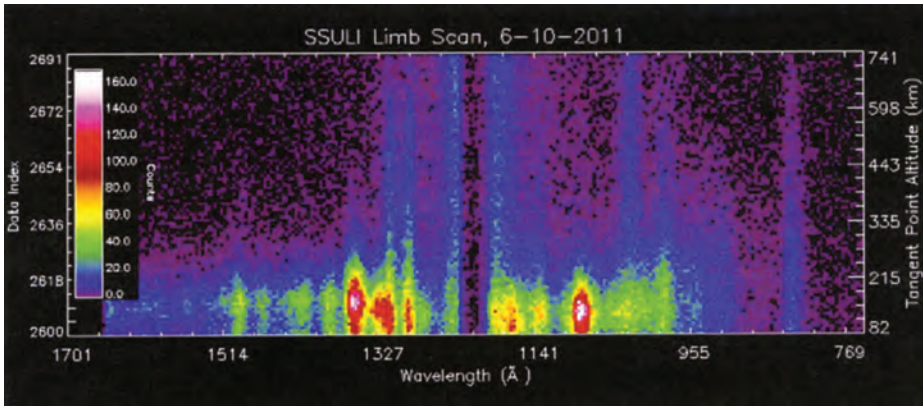
Jaffe and the NEMO team, led at NRL by Tom Wilson, aimed originally to build a hyperspectral imager—essentially a camera sensitive to wavelengths ranging from the infrared through the visible and beyond into the ultraviolet region—to provide unclassified imagery to the Navy as well as to the wider defense and commercial communities for which the imagery could be valuable.¹⁹ In an effort to save money, which the Clementine mission had demonstrated was possible to do while still scoring a great success, the NEMO team had its collective eyes on an existing satellite frame, or bus, from a financially strapped commercial satellite phone venture by the firm Globalstar. The company had suffered from miscalculations about the rise of cellular phone technology and the potential customer base, as well as a calamitous launch failure in 1998 that destroyed a dozen satellites at once. When the prospects for the business venture seemed rosier, a factory in Rome had been churning out the Globalstar satellite buses. During the planning stages of NEMO, these buses were just sitting on a shelf. The NEMO team procured one of these to host its hyperspectral imager, a much cheaper option than designing and building a one-of-a-kind bus.

“This was great for me,” Jaffe recalled. “I was in my 20s and I got to spend all of this time in Italy and in Germany,” said Jaffe, who was the lead on the group responsible for the test equipment that would check out NEMO before and after launch. As it turned out, when Boeing pulled out of the project in 2000, STDC could not come up with the funding it needed to participate. The project fell apart and was eventually canceled.²⁰ “We built a lot of hardware and ended up not flying anything,” Jaffe said. “It was a great project and we did a lot of development, but it ultimately fell victim to circumstances beyond our control,” he lamented.²¹

Flach, an old hand in the space business by the time Jaffe joined NCST, always counseled new hires about the many possible fates of space projects. His message, Jaffe recalled, was that a project could get canceled for a thousand reasons, so you always have to get as much as you can out of what you are doing as an educational experience and as a way to develop skills that likely will prove useful in subsequent projects. “That made it easier for me to approach a lot of these things,” Jaffe said.²²

Meanwhile, the SSULI project was humming along. And when the time came in 2003 for the first SSULI sensor to go into orbit, Jaffe desperately wanted to witness the launch of the first sensor he had worked on. So, even though he was working days, nights, and weekends, he flew out to Vandenberg Air Force Base in California for the liftoff of the DMSP satellite bearing the instrument. But—in a disappointing reality check—the launch was delayed. Jaffe’s involvement with the new Tactical Satellite 1 (TacSat-1) and other projects, however, meant there was no way he could stay out at the launch site indefinitely. He returned to NRL, and within a day or two of doing so, the SSULI-bearing DMSP satellite went up.

One consolation for missing the sound and fury of the launch was to spend time at a nearby National Oceanographic and Atmospheric Administration (NOAA) ground station in Suitland, Maryland, where he was able to see some of the first data coming in from the satellite, a sure sign that the work he had put into the SSULI project was likely to pay off. “That was very gratifying,” Jaffe said. “It is always cool when something that you had in your hands actually makes it into space. When you think about that, it is a little mind boggling.”²³



Edge View. A typical scan of Earth with a SSULI sensor looking out toward the edge of the planet produces a spectrum that indicates the intensity of emissions of different wavelengths at different upper atmosphere altitudes.

The disappointment of missing his first SSULI launch in 2003 was more than compensated for a few years later: within a two-week period in the fall of 2006, Jaffe witnessed two launches of sensors he had worked on at NCST. The first, a NASA mission with a two-satellite system built by the Johns Hopkins University Applied Physics Laboratory, launched with a Delta II booster on October 25, 2006, from Cape Canaveral in Florida. Known as STEREO (Solar Terrestrial Relations Observatory), the twin satellites serve as orbiting front ends of a space weather monitoring system for imaging and tracking solar flares in three dimensions. These sun-watching eyes in deep space make it easier to determine when a solar flare’s punch is headed Earthward or, instead, in some other less troublesome direction. Solar flares are serious events bearing high-energy particles that knock out sensitive satellite electronics and can wreak large-scale havoc on the ground by, for example, destabilizing the power grid.

The STEREO-based instrument that Jaffe worked on with colleagues at NCST and in the lab’s Space Science Division is called SECCHI-COR2. SECCHI is the Sun Earth Connection Coronal and Heliospheric Investigation package, a suite of several instruments, and the COR part of the acronym is short for “coronagraph,” an instrument that masks the bright disk of the sun to allow the dimmer coronal emissions to be “seen” by the instruments’ sensors. The SECCHI acronym maps onto the name of Father Angelo Secchi, a 19th century Jesuit priest and astronomer in Italy. Of partic-

ular relevance is that Father Secchi was pushing the art of measuring the spectra of light from stars and he was among the first astronomers to clearly identify the sun as a star, the one that happens to be nearest and dearest to Earthlings.

The technical and scientific success of the SECCHI project was augmented by a more public accolade. Although the primary value of the STEREO spacecraft is to monitor and predict solar weather events in part so that the satellite community can take precautions (such as changing the orientation of a spacecraft as one in a boat might do to minimize the effect of a massive incoming wave), one standout result for Jaffe ended up showing up on IMAX screens. Prior to STEREO and its SECCHI payloads, the magnificent IMAX film “Solar Max,” replete with epic music, had been playing at venues like the Smithsonian Institution. Released in late 2000, the movie was based in part on data from the Solar and Heliospheric Observatory (SOHO), another NASA mission for which NRL’s Space Science Division played a leading role. “I remember going to see it with a bunch of folks from the lab and afterwards I said, ‘when we finish SECCHI they are going to have to do a 3-D IMAX film because we will have 3-D imagery of the sun.’” And that is what happened: a couple of film production companies partnered with NASA and in 2007 released the IMAX film “3D Sun.” “I felt really gratified,” said Jaffe.²⁴

On November 4, 2006, a mere 11 days after he watched the launch of the STEREO satellite pair, Jaffe was on the west coast at the Vandenberg Air Force Base to witness his second dazzling launch of an instrument that he had played a role in making.²⁵ His neck craned as he watched a Delta IVM booster take a SSULI sensor, the second in the series of five, along with a half-dozen other sensors into orbit. The third SSULI would go into orbit in 2009, and the fourth in 2014.

The nation’s defense weather program suffered a major disappointment in January 2012 when the U.S. Air Force canceled the Defense Weather Satellite System (DWSS)—the follow-on program to the Defense Meteorological Satellite Program. But that did not happen before the SSULI program scored one of its greatest possible successes. After years of testing the sensors and software associated with them, the Defense Weather Systems Directorate of the Air Force Space and Missile Systems Center (SMC) recommended in June 2011 that the SSULI data should serve as input for space weather models as well as stand-alone data products that can be useful for satellite operators, telecommunications companies and services, and other military and civilian applications for which the electrical characteristics of the upper atmosphere can matter.²⁶

To go from concept to hardware to having an operational role is among the greatest rewards for those at NCST, Jaffe noted. Even when Jaffe was on a nine-year hiatus from working officially on the SSULI program, which is managed by NRL’s Space Science Division, Jaffe still got calls with questions like “Hey, what does this data point mean?”²⁷ Small as a question like that sounds, few people on Earth have the specialized knowledge and experience to answer it.

The gratification was of a very different sort when it came to the never-to-be-flown TacSat-1, for which Jaffe, along with colleagues including RF expert Chris Huf-fine, worked on electronic components. Despite TacSat-1's fate as a forever-grounded spacecraft, Jaffe pointed out that the mission "is still lauded as one of the efforts that really helped to build momentum behind the Operationally Responsive Space (ORS) concept because we were able to build TacSat-1 in less than a year."²⁸ ORS refers to the concept of building military satellites quickly and cheaply for specific tactical needs that arise, and for launch in weeks or months rather than the years it traditionally has taken to go from concept to orbit. As noted in the previous chapter, the lessons learned from TacSat-1 made it into orbit on TacSat-2 on December 16, 2006. (NRL had little to do with TacSat-3; launched in 2009 and deliberately de-orbited and destroyed in May 2012, it was primarily an Air Force project, though it included many partners.)

Jaffe continued work on the ORS concept and the Tactical Satellite series with contributions to TacSat-4, which made it into orbit in 2011 and demonstrated how satellite-based communication channels can create voice linkages and distribute tactical data and other types of information to end users in several military services. Jaffe was part of the large engineering team that included NCST colleagues, the Johns Hopkins University Applied Physics Laboratory, and many other partners, which designed the satellite's framework, the bus.

"The bus provides all of the utilities you need to be in the business of operating in space," explained Jaffe.²⁹ Hanging on it are solar panels that power up the spacecraft's batteries. It has thrusters and an attitude control system, including a star-tracker for maintaining the satellite's orientation. TacSat-4 essentially was a two-piece assembly—the standard bus and the COMMX payload (for satellite-based communication for warfighters on the move), which was designed and built to snap into the standard bus by way of a novel, versatile interface that could take on many other payloads.³⁰ It's the sort of plug-and-play trait that underlies the ORS concept.

"The whole idea with ORS was to reduce the cost of putting assets in space and to reduce the amount of time it takes to take advantage of assets you have in space," said Jaffe. The concept unfolds by building up resources on the ground, including communications, imaging, and radar payloads of different kinds and capabilities that all can be affixed to the same standard bus as the need arises. That, together with inexpensive and agile launch systems, could sum into an operationally responsive space capability, at least in concept.³¹

These are tantalizing ideas, to be sure, but they have been floating about among tidal forces that could delay their realization. In early 2012, for example, the White House budget requests for fiscal year 2013 entailed the shuttering of the ORS Office. A few months later, a Senate subcommittee and the House both reinstated funds to keep the space initiative alive.³² "This same back-and-forth over the ORS Office's funding has played out nearly annually between different governmental organizations

every year since,” Jaffe remarked. It had been a reminder of the lesson George Flach taught his mentees, Jaffe among them, that space projects could come to a screeching halt at just about any moment for a thousand different reasons.

Jaffe’s colleague, Carl Ford, who can list microbrewing along with his space technology credentials, prepared a pair of brews called “Standard Bus Stout” and “COMMx Bitter” to celebrate the work his NCST colleagues and their partners had devoted to the TacSat-4 payload. Jaffe noted that the two “could very appropriately be combined to make a Black and Tan since COMMx and Standard Bus were combined to make the TacSat-4 spacecraft.” Added Ford: “It’s noteworthy that Standard Bus was heavy, like a stout, and COMMx featured occasional moments of bitterness.”³³

Even though the Space Age now is 60 years old, it can’t help but attract those with visionary tendencies, and elicit bold ideas from those working on the nitty-gritty engineering of space components and systems. “When Arthur C. Clarke talked about communications satellites back in the 1940s, before anyone had even put up a satellite, people thought that sounded crazy,” Jaffe pointed out in defense of a “crazy idea” that he and others have had on a mid-burner for years: space solar power.³⁴ The idea is to collect solar energy from enormous reflective surfaces in space, concentrate it, and then beam it down via microwaves or lasers to collection systems on the Earth’s surface that can store that energy.

The concept dates back to the 1960s and both NASA and the Department of Energy invested considerable sums of money in it during the energy crisis of the 1970s. One historical incarnation of the technology centers on a solar collecting surface that is 10 kilometers long and 1 kilometer across, an area of almost 4 square miles.³⁵ It would require hundreds of materials-ferrying launches and vast expense, which is why it has yet to make it beyond the concept stage. Crazy as it seems, someone in some government agency revisits the concept every 10 years or so. In October 2007, for one, the Department of Defense’s National Security Space Office released a study suggesting that beaming solar energy from space would enable the military to do away with dangerous fuel transports to their forward operating bases in war zones.³⁶

Subsequently, Jaffe and an NCST team conducted a technical assessment of what it would take to build a space solar energy collection system. Publicly released in 2009, the report—prepared by nearly 30 NRL scientists and engineers within NCST and other lab divisions, as well as several contractors—concluded that such a system indeed could have some military applications and so was worth at least keeping in the bin of ideas. The report also noted that it would be prudent for NCST to remain engaged in the field, futuristic as it might be, by keeping up with developments and going to relevant meetings. This way, noted Jaffe, “If someone says ‘hey, should we really drop like \$100 million on technology development related to space solar power,’ we would have the knowledge base for advising, or we could say ‘yes, but you should focus here or there because you might then get a spinoff application for some other less far-fetched idea.’” It is akin to the consulting role NCST staff routinely has played

for the National Reconnaissance Office where the NRL space technologists often have been detailed to oversee the development and acquisition of complex, expensive, and highly classified systems from industry partners.³⁷

In his own thinking about space solar energy systems, Jaffe has been exploring lasers as a possible alternative to microwaves as the means of conveying the collected solar power to the surface. Remarked Jaffe, “If you use laser beams, you don’t need the enormous antennas and you don’t have to deal with things like getting frequency allocations from the Federal Communications Commission [FCC] that you do for the high power microwave approach.” That doesn’t address the issue of atmospheric sapping of the energy as it beams down to the surface, or the possible political implications of sending a high-power laser beam to Earth from space. The space solar power concept will likely continue to be a point of fascination for Jaffe, with its prospect of continuous, globally redirectable power without fuel. “There are so many little sub-areas you could do research on,” Jaffe noted, and so “there’s a unique opportunity to ‘boldly fly what never has flown before.’”³⁸ For example, Jaffe and a team of researchers from NRL’s Radar Division and Electronics Science and Technology Division built and tested what Jaffe rates as “the world’s most efficient sunlight-to-microwave conversion module.”³⁹ It goes by the name U-PRAM, for Photovoltaic DC to RF Antenna Module. He got double duty out of the work by using it as the basis for his Ph.D. dissertation; he was awarded his degree in December 2013. “NRL did a press release on the work that went somewhat viral,” Jaffe noted.⁴⁰ “It was picked up by Wired, Der Spiegel, The Daily Mail, and others. I was interviewed on MSNBC.”

“One crucial point in the U-PRAM project and essentially all NCST projects is the depth of expertise on the teams,” Jaffe stressed. “For U-PRAM, even though I was the [Principal Investigator], the project would never have succeeded without support from other folks in NCST and at NRL. Whenever you run into a tricky challenge, it seems there is always someone you can turn to or someone who knows another NRLer that can help out. This is a huge, huge benefit of being at a multidisciplinary research facility. Heck, I had a student who got a patent even before I had my first one, in large part because he asked the right questions and NRL had the right people for him to talk to!”⁴¹

Another acronym in the list of projects Jaffe has worked on is MIS, for Microwave Imager Sounder—the follow-on sensor to the Windsat microwave sensor that the Department of Defense has been using for a decade or so to map out wind speed and direction on the planet’s oceans. Since about 2008, Jaffe has spent much of his time as the lead electrical engineer for MIS, which also can gather land-based data crucial for remotely assessing soil moisture content, a key measurement for planning ground operations in which the wheels of a war machine would be rolling over various terrain types. “If you are in Afghanistan and you have to drive 400 kilometers, knowing if you will be going over hard-packed dry earth or three inches of mud will help you figure out how long it is going to take,” Jaffe explained.⁴² In yet another instance of Flach’s

cautionary attitude about the progress of space missions, the MIS project went on an indefinite hold as of September 2013.

Chris Huffine is another prolific and accomplished member of the younger generation working for NCST in the massive Building A59. Huffine is an NCST radio frequency engineer who is credited with moving software defined radio (SDR) technology (also referred to as Software Reprogrammable Payload, or SRP) into new arenas such as unmanned aerial vehicles (UAVs).⁴³ When he began working for NCST after a trial run as part of a cooperative electrical engineering program with Marquette University, Huffine was working for George Price—a branch manager in Bob Eisenhower's Space Systems Development Department—in a ramshackle, World War II-era building near the lab's front gate along Interstate 295. Price, the second-generation NRLer whose father was part of the GRAB and Poppy projects, had a knack for hiring good people and then giving them the freedom to solve problems as they saw fit.



Radio Head. Electronic engineer Chris Huffine shows off hardware from the Software Reprogrammable Payload (SRP) project for which he has led development and testing. SRP relies on software to enable a radio to emulate, and interoperate with, many of the radios in use throughout the military. (NRL photo 140910-N-JF840-003)

Huffine's first assignment was to work on software for satellite ground stations that could predict and model the emission and reception patterns of different antennas. It was part of the lab's perennial challenge of calibrating the electromagnetic emission and reception traits of space assets in orbit with key components of the system, such as command and control systems, on the ground. It was work that put Huffine squarely into the bailiwick of electronic engineer Wendy Lippincott, one of NCST's master antenna engineers. It also placed him within the globally expansive realm ruled by mathematician and software engineer Windie Borodin, manager of the 158-acre Midway Research Center (MRC) satellite calibration facility headquartered adjacent to the Marine Corps Base in Quantico, Virginia. The MRC got its name

from a Marine Corps housing area there named after the Pacific island Midway. A linear triplet of blue, 100-foot radomes marks the facility as undoubtedly part of the Space Age's infrastructure.

Huffine followed the antenna calibration software work with hardware development by way of a task to refurbish a legacy calibration device, called Scripted Emitter. He learned later these devices were originally housed inside the very same huts in which GRAB and early Poppy operators communicated with NRL-made ELINT satellites beginning in the early 1960s. This new project for Huffine unfolded before anything about GRAB had been declassified in 1998, so at first he knew nothing about the history of the huts when he was working on the refurbishing project. He recalled spending a lot of late nights and early mornings at the MRC, much of the time waiting for satellites to fly overhead.

He moved from there onto a next-generation calibration package called Pulstar. Each unit was housed in a shipping container like the ones used in trucking and railroad transportation, only it had a radome on top. Huffine built and deployed a half-dozen or so of these around the world, including on remote islands such as Guam and Diego Garcia, a long-time central Indian Ocean location for military assets. "Join NRL and see the world," Huffine said with a smile during an interview.⁴⁴

By about the turn of the millennium, Huffine was transitioning, in his words, "into some efforts looking at predecessors of Maritime Domain Awareness." "There were a variety of programs going on in our branch, in the early 2000s, in which we were looking at how to transition space technology down here," he noted, referring to the institutional drive to diversify NCST's product and customer base, mostly by way of tactically relevant technologies in the command, control, communications, computers, and intelligence (C4I) category.⁴⁵

"One big thrust was how do we take these [radio frequency] components, receivers and other things we built for spacecraft and put them into ground-based collector systems," Huffine recalled. Among them were the Choke Point Monitoring systems that harvested ELINT data from vessels passing through narrow traffic lanes such as the English Channel and the Strait of Gibraltar. Out of that emerged, in the 1980s and into the 1990s, the Story Finder system, which was the Navy's name for an ELINT system on EP-3E Aries II electronic warfare and reconnaissance aircraft. "There is a cool symmetry here," noted Huffine, referring to the repurposing of technologies first designed for and deployed in space so that they can work for surface-based applications. "WD-40 was a great lubricant for the Saturn 5 rocket and now you buy it at the hardware store," Huffine offered as a rough analogy of the space-to-ground technology transfer that NCST has been doing.⁴⁶

The EP-3E Aries II is a sizeable aircraft with four turboprop engines and enough space to accommodate more than 20 crew members, so there was no particular need to shoot for a small package with Story Finder. That changed dramatically following the terrorist attacks on September 11, 2001, after which national security planning

called for an enormous burst of additional intelligence, surveillance, and reconnaissance efforts. This included stepped-up deployment of UAVs with various sensor capabilities. UAVs are generally much smaller than manned aircraft, so Huffine and his colleagues found themselves with the task of rebuilding the capability of a Story Finder system originally designed for large aircraft into smaller, lighter, and more power-efficient packages. The theme of miniaturizing a roomful of technology into a portable box has been central in the history of NCST for several decades.

“We took what was required to do a certain electronic and processing job in the past, looked to see what kinds of advances in electronics we could leverage, and then miniaturized the system,” said Huffine.⁴⁷ The resulting ELINT package became known as Copperfield. The system was not as small as the NCST engineers would have liked, but it was smaller than the Story Finder system. They tested Copperfield prototypes on a larger-sized UAV, a Predator, at the Naval Postgraduate School in Monterey, California. With requests from sponsors for fitting yet smaller systems with the C4I package, Huffine and colleagues undertook another iteration in the miniaturization game. The result of that effort was Copperfield 2, specified with the chemical-formula-like acronym CuF2. Its modular architecture meant that it could be customized for particular jobs and situations. “You could have the ELINT module, a GPS module, an image capture module,” Huffine explained. “It was much more flexible.”⁴⁸

As the engineering vision for the ELINT package shifted from the original one, which focused on the EP-3E Aries II aircraft, into a more flexible, reconfigurable payload that could readily be made suitable for many platforms, NCST engineers continued to make performance balances and adjustments that would “future-proof” the system from the risk of obsolescence. It was designed to be evolvable. “With the broader capability designed into the hardware and software, CuF2 became a core product and acted as a springboard to a number of other unforeseen projects, each program adding further capability valuable to follow-on work,” Huffine explained in an article in the *2009 NRL Review*.⁴⁹ As the decade progressed, a veritable library of software and hardware modules became the basis for a mix-and-match system for customizing CuF2 systems for aviation, space, subsurface, and ground platforms.

This falls under the design ethic of “solving the problem once.” The idea is to keep in mind during design tasks the more extreme thermal, radiation, mechanical, vibrational, and other stresses that electronic and other components might be subjected to in foreseeable ground, air, and space applications. Then, leverage that foresight with technologies like Software Reconfigurable Payloads (yet another term for Software Reprogrammable Payload and Software Definable Radio) that enable payloads to dramatically switch functions on the fly—say, from ELINT to plane-to-plane communication. That way the same overall architecture can be deployed all over the battlespace.

One example is the Copperfield 2 system Huffine and his group designed for UAVs. They space-hardened the electronics so that a single hit from a high-energy

particle—either from cosmic or human-made sources—wouldn't take out the entire unit. They also wrapped in additional software, and environmental, vibration, and thermal testing. Then they got the green light to install it onto TacSat-1, the tactical satellite that ultimately never launched. When the Copperfield 2 unit did get into orbit on TacSat-2 in 2006, it proved itself. “We flew that and got good data,” including captured data from ships' Automatic Identification System (AIS) units, Huffine said.

The Software Reprogrammable Payload concept has expanded since then. “You can talk to the aircraft, you can talk to the guys in the squad on the next hill [even when] there is a mountain between you, you can talk to your commander back at the forward operating base and say, ‘Permission to do this?’” Huffine noted in an NRL statement in 2014 providing updates on the SRP program. “You can talk to the intel guys; you can say, ‘Hey, we hear suspicious chatter going on.’”⁵⁰

Moreover, the NRL SRP team envisions SRP-equipped Marine Corps aircraft eventually summing into a “string of pearls” type of communications network that could provide “reach-back capability” to any warfighter anywhere in the world and even when satellite communications might not be an option. Also key for making all of this work are comprehensive security measures throughout the system—from data and software encryption to hardware protection. “There's a whole architecture that's designed to protect the box against intrusion or any sort of malware or things like that,” said Huffine.⁵¹

In 2012, the SRP team pulled off a major demonstration of the overall interoperability that SRP promises at the Marine Corps Air Station Yuma in Arizona, the premier training facility for Marine Corps aviators. With an SRP-equipped KC-130 aircraft serving as the reach-back communication hub, “we were linking Yuma with Twentynine Palms, which are 150 miles apart or so; we were collecting SIGINT from 200 miles away, in the Pacific Ocean; we were doing SINCGARS [communications] relay,” Huffine recounted. “We got to do the full Monty; everything was working.” The team has done similar demos with MV-22 Osprey tiltrotor aircraft, unmanned aerial vehicles (or drones), and Humvees.

Those who work with Huffine point out that he has Howard Lorenzen-like tendencies, which is to say he has a knack for building relationships with, in Jaffe's words, “folks at the Pentagon and those actually involved in military operations. He also has remarkably sharp technical skills for someone who's such a good manager. This is partly because he does all sorts of electronics and engineering projects at home.”⁵²

That last trait applies to yet another of NCST's young Turks: senior engineer Dr. Carl Glen Henshaw, who works in NCST's Spacecraft Engineering Department. In 2012, he joined VIPs in the rollout of a brand new Laboratory for Autonomous Systems Research (LASR) on NRL's campus. The gleaming new facility illustrates the role that the Navy and Department of Defense expect robotic systems to play in the future of defense technologies, including space systems. The LASR includes a high bay rigged with multiple camera and sensor systems for analyzing the motion and be-

havior of autonomous systems, a greenhouse with a simulated East Asian rain forest that can rain at a rate of 6 inches per hour, a simulated desert environment, and a shallow pool in which researchers can test prototypes of underwater vehicles, sensors, and energy-harvesting systems. With his focus on space robotics, Henshaw finds himself sometimes in this new lab, and sometimes in the high bay of Building A59.



Space Robotics. Surrounded in his office by pictures drawn by his children, Henshaw has extended his boyhood interest in computers and robotics into space-based robotics projects, including ones focused on salvaging valuable intact antennas from otherwise “dead” spacecraft and for delicate on-orbit maneuvers between spacecraft, including grabbing with a robotic arm. (NRL photo 110411-N-4822H-002.jpg)

Henshaw, who has been with NCST since 2004, is living out a boyhood dream. Henshaw grew up on a farm and became familiar with traditional farm machinery, but at college ended up with three friends at Brigham Young University in Provo, Utah, who all loved building robots. In the 1980s, the quartet bought one of the first personal computers to become available, a Commodore, and Henshaw began learning how to use it for command and control of robots. “I knew even then that I wanted space robotics to be what I was going to do,” he recalled.⁵³

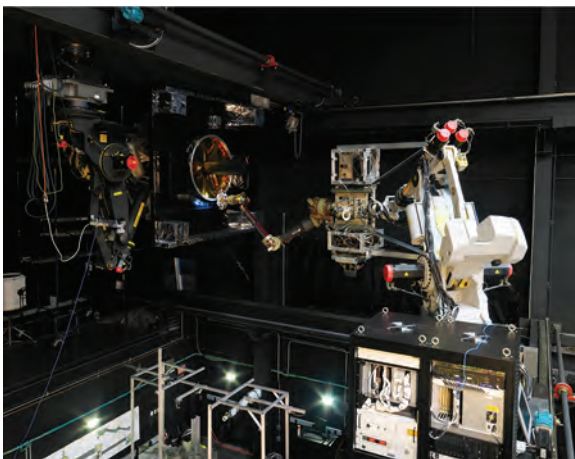
When he arrived at NRL, Henshaw found himself at a fascinating and troubling phase of the nearly half century old Space Age: there are so many defunct spacecraft, satellite components, and junk of all kinds and sizes, particularly in low Earth orbit, that sending up new assets could become like crossing an interstate highway at rush hour. There are about 5,000 intact satellites alone circling Earth in various orbits. The smaller rocket pieces and other debris, ranging in size from tiny paint chips to bowling-ball sized killers to yet more massive obliterators, number in the hundreds of thousands range. The NASA Orbital Debris Program Office puts it this way: “More than 21,000 pieces of orbital debris larger than 10 cm [centimeters] are known to exist. The estimated population of particles between 1 and 10 cm in diameter is approximately 500,000. The number of particles smaller than 1 cm exceeds 100 million.”⁵⁴ Unless this space debris can be reduced and managed, Henshaw and many others in the space business, including retired NCST director Peter Wilhelm, say it will get

to the point where your next payload might make it to orbit or it might get smacked by a tens-of-thousands-of-miles-per-hour piece of debris that turns it into the newest plume of space junk. And then the new debris from that destroyed payload will make it all that much riskier to send up the next payload. Every now and again, occupants of the International Space Station are ordered into a docked Soyuz capsule in case a piece of debris on an uncomfortably close trajectory actually hits the ISS in a way that would require an emergency escape.⁵⁵

So one of the primary aims of Henshaw and his NCST colleagues, and partners elsewhere, is to build space robotic systems—he calls them robotic space tow trucks—that can latch onto obsolete satellites and other forms of space junk and haul them out to a long-term parking orbit (often referred to as a graveyard orbit) far above the geosynchronous altitude of 22,236 miles, a popular orbital location for functional satellites. In a graveyard orbit, the junk is out of the way of new, functional satellites and their location and motion are far more predictable.

For their initial foray into this part of NCST's overall space technology portfolio, Henshaw and his NCST partners wrote up a feasibility study that landed them \$500,000 in seed money in 2003 from the Defense Advanced Research Projects Agency (DARPA), the visionary R&D agency established in 1958 in the shadow of Sputnik 1 with a mission to help the United States remain on the leading edge of military technology. Over the next few years, additional engineering analyses began to make the vision of space robotics for shuttling, repairing, upgrading, and otherwise manipulating orbiting satellites more than merely visionary. Taking the next step, DARPA green-lighted the procurement of flight-quality hardware for lab studies in Henshaw's sometimes dark-as-space high bay in Building A59. The particular DARPA program Henshaw became part of in 2008 was known as FRENED, for Front End Robotic Enabling Near-Term Demonstration.⁵⁶

“The task was to build something that would be general purpose and work with all satellites,” almost all of which had not been pre-designed for servicing, Henshaw



Robot Practice. In a high bay of Building A59 called the Proximity Operations Testbed, NCST engineers conduct full-scale tests of robotic grappling and manipulation using models of spacecraft. They can test flight mechanisms, sensors, robotic manipulators, and control logic under realistic orbital conditions. (NRL photo DARPA_NRL_FRENED-DEMO4-Image4.jpg)

remarked while standing next to a robotic arm delivered by Alliance Spacesystems (acquired by a company now known as MDC US Systems) of Pasadena, California, a collaborating company in the FRENDD project.⁵⁷ “This capability allows nearly any satellite to be repositioned on-orbit and provides a number of national benefits including better ground coverage in times of crisis, satellite life extension by eliminating the requirement imposed on fully functional satellites to expend their fuel to move to a safe disposal orbit, and disposal of derelict spacecraft which present navigation hazards to active satellites,” Henshaw and colleagues at NCST and partner firms explained in the *2008 NRL Review*.⁵⁸

Not only was the all-purpose requirement of latching onto any satellite an obvious challenge because of the structural differences in the many satellites that need to be grabbed and ushered to a graveyard orbit, but the great distance of that orbit, even beyond geosynchronous orbits, would also pose an issue. “We found out early that there is a two- to ten-second delay in command and control signals for robots at geosynchronous distances,” Henshaw said, and this meant there could be no real-time maneuverability despite the required precision of the grappling procedures.⁵⁹ This meant that Henshaw and his colleagues had to build in autonomous operations by way of an assemblage of machine vision, laser-based proximity sensors, nuanced grappler and thruster controls, and sequencing algorithms for making moment-to-moment adjustments in the control and motion of the robotic grappler.

In 2008, according to the agreement with DARPA, if Henshaw and his NCST team were to move forward, they needed to find a partner, one who would provide 50 percent of the several million dollars it would take for conducting a more involved series of in-lab demonstrations, as well as for developing control software and simulation development. The project was speculative enough and its timeline far off enough that attracting a partner willing to put skin into this game proved to be difficult. But Henshaw was convinced of the vision’s potential, a conviction that helped him keep the NCST team intact by securing a share of the 6.2 research and development funding that the Office of Naval Research designates for NRL. “This was a harrowing pitch,” Henshaw recalled. “You get one chance per year and each branch gets one project to pitch.” The 6.2 money that the robotics project received was sufficient to keep Henshaw and a handful of NCST coworkers on the task.⁶⁰

In the meantime, DARPA segued from FRENDD into a more ambitious follow-on vision called Phoenix with the goal of developing technologies to, in the words of DARPA’s web site, “cooperatively harvest and re-use valuable components from retired, nonworking satellites in [geosynchronous orbit] and demonstrate the ability to create new space systems at greatly reduced cost.”⁶¹ As DARPA’s Director at the time, Regina E. Dugan, stated it, “If this program is successful, space debris becomes space resource.”⁶² The technology could open up cost-saving options in which new, small, and relatively cheap satellites could be launched and then fitted with massive, already built antennas robotically recovered from the graveyard orbit as though they were

salvageable parts in a car junkyard. The overall value of satellites already languishing in the graveyard orbit amounts to more than \$300 billion, according to DARPA.

The vision of turning space junk into a vast resource using fleets of robots and on-orbit recovery and construction devices is currently unproven and far from deployment. But the NCST space robotics team continued to work on the pieces that would all have to come together. Among these was the Low Impact Inspection Vehicle (LIIVe) program. The team developed algorithms and overall protocols that would enable a small satellite to inspect disabled satellites from a distance of a human arm's length, a meter or so. Also, NASA has adopted the same technology for use in its small satellite program known as SPHERES, an acronym for the inelegant, long-form name: Synchronized Position Hold, Engage, Reorient Experimental Satellites. Built by engineers at MIT, the SPHERES, which look like boxy soccer balls (and are about that size), are designed to fly in formation and to serve as sensor-equipped assistants to astronauts.⁶³

Henshaw is a natural for this work. He said his robotics interests, spanning back to his hobbyist days, impressed upon him that nothing about the hardware or software challenge is easy or for anyone who is easily frustrated. "I had built robots from scratch before becoming an expert," he said. Now, in addition to his homegrown and long-term work with robotic systems, he has computer science and aerospace engineering credentials from the University of Maryland also under his belt. "Systems engineering has grown organically in my brain and hands," he said in an interview, noting that creating complex systems that work is what NCST always has been about. Said Henshaw as he looked up at an experimental set-up in his A59 high bay, "we are good at systems engineering, at putting it together."⁶⁴

Chilbert, Jaffe, Huffine, and Henshaw, as exceptionally productive as they have been, are merely representative of the many hundreds of engineers that have been part of the NCST narrative. The accounting of all projects, spacecraft, and other systems with some piece of hardware, software, know-how, or other aspect of NCST's portfolio inside would take many volumes to complete. They would dwarf the NCST manifest of 100 satellites and payloads. Says Jaffe, "there are plenty of things that don't show up there because they didn't have their own launch or they were not their own satellite. We have worked on a lot of projects also that didn't really end up going into space, but they still are things people spent a lot of time and effort on. I don't know how you count those, but they all count."⁶⁵

¹ For an NRL article on milestones, see <http://www.nrl.navy.mil/media/news-releases/2011/nrl-center-for-space-technology-reaches-century-mark-in-orbiting-spacecraft-launches>; for a timeline of NRL space projects, see <http://www.nrl.navy.mil/media/publications/65-years-in-space-a-time-line/pages/65-Years-In-Space-Timeline-NRL.pdf>.

² Aaron Chilbert, interview with author, February 21, 2012.

³ Aaron Chilbert, interview, 2012.

⁴ Aaron Chilbert, interview, 2012.

⁵ For an NRL fact sheet on MPTB, see <http://www.nrl.navy.mil/research/nrl-review/2004/space-research-and-satellite-technology/clark/>.

⁶ Aaron Chilbert, interview, 2012.

⁷ T.G. Kawecki, G.G. Golba, G.E. Price, V.S. Rose, and W.J. Meyers, *IEEE Trans. on Microwave Theory and Techniques*, vol. 44, p. 1198 (1996).

⁸ James Winkler, My Career at the Naval Research Laboratory, 2012.

⁹ Donald U. Gubser, "US Navy's Superconductivity Programs: Scientific Curiosity to Fleet Utility," *IEEE Transactions on Applied Superconductivity*, 21(3), pp. 931–935 (2011).

¹⁰ Aaron Chilbert, interview, 2012.

¹¹ Paul Jaffe, interview with author, February 28, 2012.

¹² http://appel.nasa.gov/wp-content/uploads/sites/2/2013/05/NASA_APPEL_ASK_27s_nuts.pdf.

¹³ Paul Jaffe, interview, 2012.

¹⁴ Paul Jaffe, interview, 2012.

¹⁵ Paul Jaffe, interview, 2012.

¹⁶ See, for example, <http://www.nrl.navy.mil/media/news-releases/2014/nrl-to-launch-ssuli-on-april-3rd-will-measure-ionosphere-electron-density>.

¹⁷ Paul Jaffe, interview, 2012.

¹⁸ Paul Jaffe, interview, 2012; United States Court of Appeals for the Fourth Circuit (Unpublished), No. 05-1671, Space Technology Development Corporation; Earth Search Sciences, Incorporated; Accuprobe, Incorporate, vs The Boeing Company; Argued September 19, 2006, and decided on December 12, 2006.

¹⁹ See, for example, <http://www.globalsecurity.org/space/systems/nemo.htm>.

²⁰ Paul Jaffe, interview, 2012; United States Court of Appeals for the Fourth Circuit, 2006.

²¹ Paul Jaffe, interview, 2012.

²² Paul Jaffe, interview, 2012.

²³ Paul Jaffe, interview, 2012.

²⁴ Paul Jaffe, interview, 2012.

²⁵ For launch specifications, see http://space.skyrocket.de/doc_sdat/dmsp-5d3.htm.

²⁶ NRL Press Release, "NRL Instrument Provides Key Space Weather Data", June 22, 2011, <http://www.nrl.navy.mil/media/news-releases/2011/nrl-instrument-provides-key-space-weather-data>.

²⁷ Paul Jaffe, interview, 2012.

²⁸ Paul Jaffe, interview, 2012.

²⁹ Paul Jaffe, interview, 2012.

³⁰ Michael Hurley, William Raynor, and Kenneth Weldy, "TacSat-4 COMMx, Advanced SAT-COM Experiment," Naval Research Laboratory (Washington, DC, 2009).

³¹ Paul Jaffe, interview, 2012.

³² See, for example, <http://www.spacepolicyonline.com/news/sasc-adds-funds-for-ors-stp-and-commercial-imagery-purchase>.

³³ Paul Jaffe, correspondence with author, July 2014; Carl Ford's quote was supplied by Jaffe.

³⁴ Paul Jaffe, interview, 2012.

³⁵ See NASA/DOE studies of the concept, for example, <http://www.nss.org/settlement/ssp/library/1978DOESPS-ReferenceSystemReport.pdf>.

³⁶ National Security Space Office, "Space-Based Solar Power As an Opportunity for Strategic Security" (a feasibility study), October 10, 2007, <http://spacesolarpower.files.wordpress.com/2007/11/final-sbsp-interim-assessment-release-01.pdf>.

³⁷ W. Neil Johnson et al., "Space-based Solar Power: Possible Defense Applications and Opportunities for NRL Contributions," NRL/FR/7650--09-10,179, October 23, 2009; <http://www.nss.org/settlement/ssp/library/2008-NRLSBSP-PossibleDefenseApplicationsAndOpportunities.pdf>.

³⁸ Paul Jaffe, interview, 2012.

³⁹ Paul Jaffe, correspondence with author, July 2014.

⁴⁰ <http://www.nrl.navy.mil/media/news-releases/2014/solar-power-when-its-raining-nrl-builds-space-satellite-module-to-try>.

⁴¹ Paul Jaffe, correspondence with author, July 2014.

⁴² Paul Jaffe, interview, 2012.

⁴³ Chris Huffine, interview with author, March 22, 2013; see also <http://www.nrl.navy.mil/media/news-releases/2014/software-reprogrammable-payload-srp-nrls-airborne-box-brings-connectivity-jamming-to-troops-in-remote-areas>.

⁴⁴ Chris Huffine, interview, 2013.

⁴⁵ Chris Huffine, interview, 2013.

⁴⁶ Chris Huffine, interview, 2013.

⁴⁷ Chris Huffine, interview, 2013.

⁴⁸ Chris Huffine, interview, 2013.

⁴⁹ Chris Huffine, “Cross-Domain Payload Migration,” *2009 NRL Review* (Washington, DC: Naval Research Laboratory, 2009), pp. 172–174.

⁵⁰ <http://www.nrl.navy.mil/media/news-releases/2014/software-reprogrammable-payload-srp-nrls-airborne-box-brings-connectivity-jamming-to-troops-in-remote-areas>.

⁵¹ <http://www.nrl.navy.mil/media/news-releases/2014/software-reprogrammable-payload-srp-nrls-airborne-box-brings-connectivity-jamming-to-troops-in-remote-areas>.

⁵² Paul Jaffe, correspondence with author, July 2014.

⁵³ Glen Henshaw, interview with author, March 2, 2012.

⁵⁴ <http://orbitaldebris.jsc.nasa.gov/faqs.html>.

⁵⁵ “ISS Crew’s Emergency Scramble...And We Aren’t Talking About Eggs,” SatNews.com, March 26, 2012.

⁵⁶ Glen Henshaw, interview, March 2, 2012; www.darpa.mil/WorkArea/Download-Asset.aspx?id=2147486079.

⁵⁷ Glen Henshaw, interview, March 2, 2012.

⁵⁸ B.E. Kelm et al., “FRIEND: Pushing the Envelope of Space Robotics,” *2008 NRL Review*, (Washington, DC: Naval Research Laboratory, 2008), pp. 239–341.

⁵⁹ Glen Henshaw, interview with author, March 2, 2012.

⁶⁰ Glen Henshaw, interview with author, March 2, 2012.

⁶¹ http://www.darpa.mil/our_work/tto/programs/phoenix.aspx.

⁶² See, for example, <http://phys.org/news/2011-10-satellites-the-darpa-phoenix.html>.

⁶³ NASA Press Release, “NASA ‘Smart SPHERES’ Tested Successfully on International Space Station,” http://www.nasa.gov/mission_pages/ttm/telerobotics/11-160.html.

⁶⁴ Glen Henshaw, interview, March 2, 2012.

⁶⁵ Paul Jaffe, interview, 2012.

THE HOUSE OF WILHELM

Think of Microsoft; Bill Gates comes to mind. Think of Apple; the late Steve Jobs comes to mind. Baseball: Babe Ruth.

The Naval Research Laboratory does not enjoy the kind of name-recognition that Major League sports and the biggest companies in the world do, but anyone who knows about NRL's pioneering and long-haul role in the history of American space technology will instantly recognize the name Peter Wilhelm. Wilhelm himself would balk at that characterization, knowing firsthand that it takes teamwork to achieve anything in space and because he is too humble, but the facts also do speak for themselves.

At the end of 2014, Wilhelm was deep in his 56th year as a space technology engineer, manager, and leader at the Naval Research Laboratory. On December 17, he announced in a characteristically unassuming and to-the-point e-mail, and with an engineer's flair for counting years, that he was retiring:

To Everyone in Code 8000 and the Greater NRL,

This is an e-mail unlike any I have ever sent before—and I don't know any other way but to cut to the bottom line. In typical military lingo they apparently refer to this as BLUF—Bottom Line Up Front.

I have decided to retire on 12/31/14. After 55.75 years at NRL I have put in my time. My health is still good and I would like to not have to come to work every day.

I am sure this will come as a surprise to most of you, but once I decided, I did not want to drag it out.

This has been the best career anyone could have asked for. NRL is the best place someone like me could ever work and the best part is the people that I have worked with. You all will do fine in the future and anything I can do, in my retirement, to help I will do.

Pete Wilhelm

It had been a run unlike any other. Wilhelm had continuously worked as a space engineer longer than perhaps anyone else in the in the U.S. government, which means maybe longer than almost anyone else in the entire U.S. space program since its inception in the middle of the last century.



Peter Wilhelm, an embodiment of NRL's role in the Space Age, is shown here early in his career in 1962 testing a turn-on mechanism intended for a satellite designed for calibrating the Naval Space Surveillance (NAVSPASUR) system; in his office in 1985, the year before the Navy established the Naval Center for Space Technology; and in 2012 in a ceremony marking a change in military command at the lab. (NRL photos 60807(92), P-2188(13).jpg, and 120830-N-JF840-182.tif)

In December 1959, just two years after Sputnik became humanity's first artificial satellite, Wilhelm was in the midst of designing and hand-building a transmitter that would make it into orbit a half-year later where it would send down the world's first spy data ever collected from space, as well as scientific data about solar radiation from NRL's first SOLRAD payload. Six years after that, he would be leading the Satellite Techniques Branch at NRL in an early phase of his own ascendant trajectory as one of the pioneers of the Space Age. In 1986, he became director of the then brand

new Naval Center for Space Technology, established by the Navy in recognition of NRL's leading role in the Navy's space activities, and he remained in that position until his retirement. In September 2011, when TacSat-4 soared into orbit from a launch pad in Alaska, the youthful septuagenarian Wilhelm had been a guiding force in upwards of 100 payloads, both classified and unclassified ones. Even in 2014, Wilhelm was far more apt to talk about ambitious space engineering visions—among them using “electrodynamic tethers” in systems to clean up and manage the dire problem of space debris, or the Microwave Imager Sounder (MIS), the yet-to-launch follow-on to Windsat—than to even contemplate retiring from NCST and government service.

Peter Wilhelm is one of the biggest names in space technology that most Americans have never heard of. But he has been well known to generations of NRL scientists and engineers, as well as to generations of top-echelon Navy and Department of Defense military and civilian leaders, directors of the nation's most important intelligence organizations, and Presidents of the United States, who have personally and officially commended him for his service to the country.

Many of those who have known Wilhelm most closely—his colleagues at NRL over the course of more than half a century—find it hard to overstate their admiration for him. “I consider him to be the best systems engineer in the world,” said Fred Hellrich, a senior scientist with the Office of Naval Research and a former coworker of Wilhelm's when both were building spy satellites and assembling the lab's space technology capabilities and know-how. Wilhelm's list of recognitions from officialdom has grown every year, beginning in 1962 when he earned the Navy Meritorious Civilian Service Award. A half century later, the list would include the Presidential Distinguished Rank Award, the highest award the United States can bestow on a government senior executive; the little-publicized honor of being named a Pioneer of National Reconnaissance (so far, not even 100 have been so-named by the National Reconnaissance Office, which was established in 1961); and induction into the National Academy of Engineering. The dozens-long list includes just about every award and recognition a space engineer could covet. All of this recognition matters to Wilhelm, but primarily in the way it reflects on the teams and the many hundreds of fellow engineers, scientists, managers, and technicians he has worked with over the years.

“There is a saying about ‘standing on the shoulders of giants’ that applies to my career,” Wilhelm said. “I accept all of the recognition that I have received as an endorsement of the quality of the whole program ... I feel very fortunate to have had the opportunities I had in my career. I believe it definitely was unique. I was there at the right time, and I just had a set of experiences that no one else had ... I had a very general goal in my career: I just wanted to be part of making important contributions.”¹ It is that simple in the end. Wilhelm, NRL, and NCST have made important contributions to the Space Age, to the ongoing history of space technology and the U.S. space program, and to national and homeland security. And Wilhelm has been

the Cal Ripken of NRL's space technology team, never missing a game for decades and standing out all the while. When it comes to NRL's part, he has seen it all.

Born in New York City in 1935, Wilhelm first heard about NRL when he was in junior high in Yonkers. He had read an article in *Colliers* magazine describing a truly audacious project, led by NRL radar engineer James Trexler, to build an antenna dish that was 600 feet in diameter, about 45 feet more than the Washington Monument's height.² "My gauge of distance back then was how far a home run could be hit, and I thought, even Babe Ruth couldn't have hit one this far, 600 feet."³ To top that off, he noted, this high-tech "ear" of a magnitude even Egyptian pharaohs would have admired was to be steerable from horizon to horizon.

"I'm thinking, 'wow, two football fields across and how in the heck could you get something like that that could move and everything,'" Wilhelm recalled in an interview, with excitement in his voice even more than half a century later. "I'm thinking, 'boy, they must have some smart people at that Naval Research Laboratory.'" What the article could not have revealed at that time, in the late 1950s, was something that only would have blown the young Wilhelm's mind even more: in addition to its publicly divulged role as a world-class radioastronomy observatory, the "big ear's" even more pressing role was to listen in on radio and other electromagnetic signals from the Soviet heartland after these had bounced back to the Earth from the moon. He could not have known then either that by the end of the decade he would become not just a part of this NRL that he had come to admire, but a driving force who would help elevate the lab into a major player in the U.S. space program.

As an electrical engineering student in the 1950s at Purdue University in West Lafayette, Indiana (a program he had gotten into, he says, because his aunt's sister was married to the dean of admissions),⁴ Wilhelm had heard about the Vanguard program to orbit a scientific satellite as part of the International Geophysical Year, which spanned over 1957 and 1958. "The idea of putting an artificial satellite into orbit around the earth was kind of a mind boggling thing to a lot of people, including me," Wilhelm recalled.⁵ Four months after he graduated in 1957, the Soviet Union placed the world's first satellite, Sputnik, into orbit. Wilhelm himself was coming of age in the moment of history when the Space Age was beginning.

He had just moved to Chicago where his newly wed wife at the time had landed a job as a schoolteacher. It was a move that would soon lead to his first direct contact with NRL. He had gotten his first post-college job with the Chicago-based company Stewart Warner Electronics where he was assigned to work on a Navy radar test set for submarines. It was a full-scale education for an electrical engineer. "It involved all kinds of circuitry that would later ... prove important in a lot of things," he said. "I mean it had high-voltage power supplies to run the cathode ray tube, and I worked on that. There was lots of pulse circuitry, so I learned how to design circuits like that. Audio amplifiers. Video amplifiers. A lot of delay lines for delaying a pulse."⁶ Part of this job was to test the equipment in temperatures that ranged from 40 degrees below zero

centigrade to 55 degrees above, extreme-temperature tasks that he sometimes did in his bathing suit and that once required a nurse to treat what he described as a nearly flash-frozen throat.⁷ In his first job, Wilhelm did what it took to get the job done, and he would carry that trait throughout his entire career.

The work at Stewart Warner was going well. The equipment was getting designed and built. But there was one pivotal step that had to be taken. In early spring 1959, the company sent him along with the radar test set to the Naval Research Laboratory's IFF Branch (IFF stands for Identification Friend or Foe), which had the authority to accept or reject the equipment. The very first day Wilhelm got there and began working with his NRL cohorts, Laddie Rhodes, who was head of the IFF Branch, offered him a job developing technologies to help warfighters make that all-important IFF distinction in the midst of battles. With flowers blooming and memories of the cold and snow of Chicago, Wilhelm accepted the offer. He did not even consult his wife, he admitted much later with some incredulity.

Within months of arriving, he discovered one of the traits that NRL's scientists and engineers most often tout about the lab: it has an R&D portfolio so diverse and broad that it generally is possible to find partners on site who can help you with any particular research project or challenge or with whom to pursue new research interests. Within months of working in the IFF Branch, Wilhelm found himself interviewing with Marty Votaw about another possible job at NRL. Votaw was one of the few Project Vanguard remnants⁸ at NRL who was resolved to resurrect a satellite program at the lab in the midst of the Presidentially mandated transfer to NASA of the more than 200 engineers, technicians, and managers that comprised the lab's entire Vanguard team. Before his first year at NRL was ending, Wilhelm had become part of Votaw's tiny group of first-generation satellite engineers in the brand new Satellite Techniques Branch. As Wilhelm thought about it later when he was cleared to work on classified programs, he could see that Votaw was mightily moved by the secret plans laid by Howard Lorenzen and Reid Mayo in 1958 to build an audacious new Cold War technology—spy satellites for gathering electronic intelligence (ELINT) as the spacecraft zoomed over the Soviet heartland.

“Marty realized that if we can detect these Soviet radars with our little satellite, that's a big deal for this country and I think that is why he came back,” Wilhelm explained, referring to Votaw's step of applying to return to NRL after being officially transferred to NASA as part of the Vanguard team. “He knew that was going to be really important.”⁹ And with Lorenzen as a champion of the project, it was likely to go places. Said Wilhelm: “Howard Lorenzen, as an individual, was already considered kind of the father of ELINT. He had a huge reputation and he knew everybody in the business.”¹⁰

“Looking back, if we had not been as scared as we were, I do not believe we—as a country—would have put as much effort into developing new technologies as we did,” Wilhelm said, referring to the nation's Cold War angst. “We felt like the underdog,

and I believe that was probably good for our psyche. We concluded that we could not overpower them, so we had to beat them with smarter systems and technology.”¹¹

Behind the scenes, and unknown to Wilhelm at the time, was that the titans of the lab—among them, Robert Page, the radar pioneer who had become the lab’s research director, Lorenzen, and Dr. Herbert Friedman, the top-tier solar physicist and astronomer who had managed to elude the NASA transfer—were orchestrating a spectacular comeback. When it came to space, this was a make-or-break moment for the lab. Page, for one, did not think the lab should be in the rocket engineering business per se, as it had been during the Viking and Vanguard programs. He feared that that enormously expensive and labor-intensive activity would consume too much of the lab’s funds and undermine the diversity of expertise and basic research that made the lab unique. Satellites, though, were acceptable new elements of the lab’s R&D portfolio.

Using a Vanguard-style payload, NRL’s first satellite mission after the NASA transfers would presage the lab’s dual interests in open scientific research and secret national defense R&D. It became two missions in one: Friedman and his space science colleagues would perpetuate the lab’s solar physics and upper atmosphere research with radiation-measuring instruments, and Lorenzen, with Mayo and others, would install a radar-detecting device (originally designed for submarines at sea) into the same satellite shell, thereby rendering it the first spy satellite in history. As far as Wilhelm knew at first, his entire charge was to build a little transmitter for the scientific payload—called SOLRAD, for solar radiation—that had to work at a then unusually high frequency of 136 megahertz.¹² It was an engineering problem, requiring the use of newfangled and still-unreliable solid-state transistors instead of vacuum tubes. Building the transmitter with the new transistors was a problem to solve and that is what engineers love to do. It happened to be a transmitter destined for space. “That is how I got into the satellite business,” Wilhelm said.¹³

When he joined the Satellite Techniques Branch in 1959, the branch was composed of fewer than 10 engineers working in a few rooms of Building 59, near the lab’s guarded entrance gates. The overall team included a secretary and a few additional technicians from Mayo’s branch, bringing the total count at the branch to a dozen or so.¹⁴

Wilhelm found himself in a heady context in which the lab’s well-known upper atmosphere and solar scientists, most notably Friedman and Dr. Richard Tousey, were collaborating with the Satellite Techniques Branch to build SOLRAD 1. “The satellite looked just like the [later] Vanguards—a 20-inch sphere,” Wilhelm said in an interview, adding that there still were some transistors and other usable parts from the Vanguard program that didn’t quite make their way to NASA.¹⁵ He had not yet been cleared to know about the top-secret payload that this same 20-inch sphere would shuttle around the planet when it made it into orbit on June 22, 1960.

“I had been there (in the Satellite Techniques Branch) several months, I guess, before they told me what else was going on,” Wilhelm recalled. “Up until that time, I did not know there was a second payload in the satellite.”¹⁶ Mayo, Rose, and others who were in on the classified payload would “come over to our branch at night and do their thing,” Wilhelm said. Lorenzen was “absolutely paranoid about security,” so he made sure none of his “countermeasures people were hanging out with satellite people.”¹⁷

It was Mayo who spilled the beans to Wilhelm in the spring of 1960. And it was an amazing revelation, particularly in light of the shooting down of Gary Powers over the Soviet Union in a U-2 spy plane just a month or so earlier. Said Wilhelm: “Everyone knew that trying to spy on the Soviet Union was a pretty goddam dangerous thing to be doing. And here we were doing it. So I thought that was really neat.”¹⁸ Once in the classified world, Wilhelm would never leave it, but he was driven by the sensible engineering truth that components and systems designed for any one mission, classified or not, could point to the solution for challenges of other missions, classified or not. That sort of technology transfer would characterize the next 50-plus years of satellite engineering for Wilhelm and the NRL teams he would lead.

They all would grow together through world-changing developments. When they were building SOLRAD 1 and its classified stowaway,¹⁹ most often dubbed GRAB 1, this was a momentous time in the history of technology. Side by side with the advent of the Space Age was a shift from the familiarity of vacuum-tube-based generations of electronics to the new solid-state transistors and other power-efficient electronic devices that promised to perform even better at a fraction of the size, cost, and weight. One of Wilhelm’s early tasks, to build that 136-megahertz transmitter, pushed the outer limit of the frequency that transistors were capable of generating at the time. “You would only get a few transistors out of the whole batch that would work at all,” he recalled.²⁰

Most startling to Wilhelm was the output of his little palm-sized transmitter would be less than one watt, equivalent to that of a dim nightlight. Recalled Wilhelm: “I am thinking, this is supposed to be hundreds of miles up in space and we are supposed to get a signal back. It was blowing my mind. But of course we built it, tested it, and it worked.” Wilhelm’s transmitter sent the first data on Soviet radar systems ever intercepted in space to ground stations built around the world as part of the classified GRAB program. The results turned heads in the intelligence community, which then wanted more of what the NRL team was showing it could deliver. “We started having the money to get the test equipment and facilities for building satellites, like the vacuum chambers and the vibration machines and that sort of thing,” Wilhelm said.²¹

In an early illustration of his own seat-of-the-pants and frugal style of engineering that would later score enormous successes for the space program, he even conducted his own bootleg test. When colleagues who had gone to Cape Canaveral to work on the June 22 launch of SOLRAD 1/GRAB 1 called to share the good news that the

satellite had made it into orbit, Wilhelm went to the roof of Building 59 with a small receiving antenna in hand. There was a painter's ladder up there. "I opened it up and laid it on its side to form a 'V,' and I laid an antenna on the ... ladder and aimed it in the general vicinity [of the satellite's trajectory]," he recounted, adding that he also had run a cable down to the lab where he could hook it up to a radio equipped with earphones. "By God," said Wilhelm, "just right on time, here comes the satellite. We could hear it. That was probably one of the greatest thrills I ever had. My own hands had built that transmitter and the whole episode really got me hooked" on satellites.²²

It didn't take long for Wilhelm to learn the lesson that getting into the business of leading-edge space technology was risky. The next three satellites he worked on failed to make it into orbit, all due to problems with their respective Thor Able Star boosters. "It really looked like we would just have to go out of business," he recalled, but the Air Force's new Thor Agena booster proved to be reliable enough to get things back on track. It was just one of the near-death experiences that NRL's space technology cadre would experience.

From the beginning, Wilhelm pointed out, he and his fellow engineers found ways of transferring aspects of existing technologies into the relentless flow of new ones they needed as they pioneered into the new overhead territory of space. One early technology standout, in Wilhelm's view, were the solutions the lab developed for the then-enormous problem of storing data picked up by, say, radiation and radio frequency receivers on a satellite. Ground stations were few and far between. Unless there was some way to store data at times where there was no ground station within a spacecraft antenna's line-of-sight, the satellite could essentially listen in on Soviet radar systems but not report—by way of a data dump—on what it had heard. So Wilhelm, Bob Eisenhauer, and their colleagues set out to work with industry partners to invent a memory system that would enable their satellites to pick up signals, store them as data, and then relay them to a ground station at its earliest possible convenience.

"The first attempt to use a motor to drive a magnetic belt ... turned out to be a loser," Wilhelm recalled. "We couldn't get accurate enough registration or repeatability with the mechanical motor and gears, and all the tolerance involved, to read out what had previously been recorded." The NRL engineers teamed up with a small company, Spacetac, that had been delving into a solid-state alternative—a magnetic core memory system in which each tiny donut-shaped "core" could be electrically written to, and read from, without requiring moving parts. "Together with them, we developed the first solid-state memory for the SOLRAD program so it could record the output of the X-ray detectors all around the orbit without gaps," Wilhelm said, specifying that the memory unit first flew in space in 1965.

In another illustration of the newness of satellite technology in the 1960s, Wilhelm built an entire satellite almost all by himself. The point of it was to help calibrate the pathbreaking space surveillance system (NAVSPASUR) that NRL colleagues Rog-

er Easton and Jack Mengel had designed to keep track of whatever satellites anybody, particularly the Soviets, might fly over U.S. territory. Wilhelm's satellite was one of a series dubbed SURCAL, for Surveillance Calibration, whose satellites were designed with specific and known shapes and sizes. They served as reference objects for the NAVSPASUR system so that NAVSPASUR operators could discern more details from radio echoes deriving from other objects, such as Soviet satellites. Said Wilhelm: "I basically built that whole satellite by myself. It was so small that one guy could handle it."²³ The general trend from there would be that ever-larger engineering teams would build ever-larger and more complex satellites.

Wilhelm also built an on-payload receiver to listen in on the fan-shaped radio beam transmitted from the NAVSPASUR ground stations. "When that satellite would come through the beam, it would pick up the first side lobe of this fan beam, and it would turn on and then reradiate a very strong signal down, which enabled us to essentially plot the whole beam structure of 'the [NAVSPASUR] fence,'" Wilhelm said.²⁴ Well, it would have, had it made it into orbit. The Thor Able Star booster failed during its January 24, 1962, launch attempt, sending Wilhelm's hand-built SURCAL satellite into the ocean. Joining it were two other satellites that were in the rocket's fairing: another SOLRAD satellite²⁵ for measuring solar X-rays and a payload named LOFTI intended to test whether low frequency radio signals could traverse the ionosphere intact enough to be useful for communicating with submerged submarines.²⁶ There was one additional payload on the rocket, tucked inside the SOLRAD shell: another ELINT payload that would have become known as GRAB 3 had it made it into orbit.²⁷

Wilhelm got a powerful inkling in 1965 that leadership was in his future—whether he wanted it or not! That is when Ed Dix, Wilhelm's boss and RF engineering mentor, confided that he would be following Marty Votaw, the man most responsible for preserving a satellite technology beachhead at NRL, into the nascent commercial satellite communications industry by taking a job at COMSAT.²⁸ Wilhelm already had become head of the Satellite Instrument Section, but he did not think he was quite up to the role of running the entire Satellite Techniques Branch. Ed Dix thought otherwise and told Wilhelm he thought he was the logical choice.

After all, as head of the Satellite Instrument Section, Wilhelm was getting a feel for all aspects of a satellite—including mechanical, electrical power, and RF communications components and systems. "It kind of got me in touch with everything that went into a satellite," Wilhelm said. Without being intentional about it, he was becoming a noticeably capable and innovative systems engineer who would earn the admiration of so many in the years to come. The promotion from section head to head of the Satellite Techniques Branch was not a done deal: there had been no precedent at the lab for the leap in rank and pay grade that Dix was envisioning for the young Wilhelm, whose own heart remained on the bench. He was not himself pining for administrative responsibility.

In fact, the lab's leadership was inclined to conduct an external search, a move that would have delayed the addition of an administrator's hat for Wilhelm. But the prospect of finding someone from the outside to airdrop in and supervise the tight-knit satellite group did not appeal to anyone in the branch. Without Wilhelm's knowledge, every engineer in the branch signed a petition in support of hiring him as head of the branch and they delivered their petition to the top-tier of the lab's leadership in Building 43. The petitioners were successful. Wilhelm got the promotion and suddenly became the leader of the Satellite Techniques Branch that by then had grown to about 30 staff members. It would grow to more than 10 times that staffing level in the years to come. This set Wilhelm into a course of taking on ever more administrative and programmatic responsibility, even as he strove to keep his engineering skill set actively engaged in the mix.

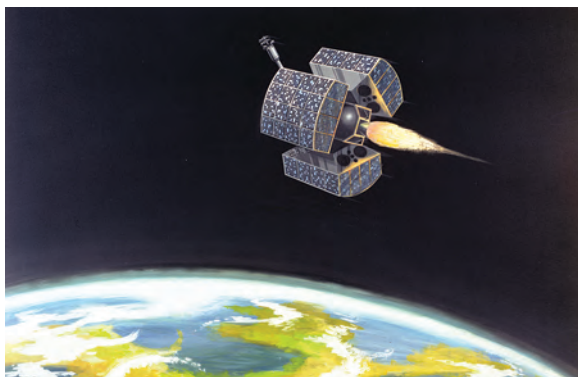
When he took over as head of the Satellite Techniques Branch in 1965, the work was split between unclassified projects in collaboration with Friedman, Tousey, and their space scientist colleagues, on the one hand, and on the classified ELINT program that was sponsored by the National Reconnaissance Office, on the other hand. Both programs were earning a top-notch reputation for the laboratory, but the classified side also was winning over those in a position to seek and deliver the substantial financial support that it took to run these expensive programs. "We really started demonstrating some things that some people in the military realized could not be done any other way," recalled Wilhelm.²⁹

NRL's space science and space technology groups both grew up together from the post-World War II years in the 1940s when the lab was using captured V-2 rockets to loft measuring instruments to unprecedented heights in the upper atmosphere. But two decades later, as Wilhelm's responsibility was on the rise, there was at least a partial divergence of the two arenas—space science and space technology—in the offing. In the years leading up to Wilhelm's big promotion, the ELINT team was building its classified payloads to detect more and more bands of radar, which they could only do by packing more circuitry and other components inside. "It started to get tight inside that little sphere," Wilhelm recounted. The original 20-inch sphere hosting the dual SOLRAD 1/GRAB 1 payloads gave way to a 24-inch diameter shell and then to a version with a stretched belly. Add to that the need for SOLRAD experiments to have a platform pointing toward the sun, whereas the ELINT payloads were naturally earthward-pointing missions, and the idea that the two missions might have to be physically separated onto different platforms readily came to mind.

"You could see it coming that basically these two payloads are not compatible with each other," Wilhelm recalled. "We could not optimize either one because of the such different missions. So really the two missions needed to kind of go their own way."³⁰ It was time for the space science and space technology elements of the laboratory, which remained merged by necessity after the Vanguard team transferred to NASA, to begin taking independent trajectories.

In 1971, the lab undertook a major administrative reorganization by which Wilhelm's Satellite Techniques Branch fell under the wing of Howard Lorenzen, who with Reid Mayo had secured the lab's pioneering place in the history of space-based ELINT. Lorenzen at the time was head of the lab's Space Systems Division (one of four divisions in the Space Science and Technology Directorate under the leadership of Herb Rabin). And unlike Wilhelm's previous boss, Dr. William R. Faust, who was not so interested in satellites, Lorenzen saw a big future in space. Said Wilhelm of Lorenzen: "He was dedicated to the space effort and was a real hard-charging guy ... He let me pretty much run my show, but he supported me very strongly, and brought in some real major programs for the Navy that were very successful ... Lorenzen had quite a good reputation in his own field [of electronic countermeasures]. That was probably one of the significant steps that we made that put the space program on a growth curve."³¹

This was an expansive time for NRL's satellite cadre. From the early to middle 1970s, they were working simultaneously on three major programs: the scientific SOLRAD program, including SOLRAD Hi, a satellite pair whose circular orbits took them out to 60,000 nautical miles from the surface; the Timation navigation program that Roger Easton had devised and that would demonstrate the key technologies underlying the Global Positioning System (GPS); and a new program, the Multiple Satellite Dispenser (MSD), that was an evolutionary step in the classified ELINT program and that would lead to its own consequential lineage of technologies. "The NRL space program was getting lots of attention from lots of different quarters," Wilhelm noted.³²



Multitasker. NRL space technologists developed the Multiple Satellite Dispenser, depicted in orbit in this drawing. The MSD could deliver several individual payloads into distinct orbits. (NRL photo 76549.jpg)

As if the challenge of running three major programs while undergoing a reorganization was not enough to keep Wilhelm busy, he also learned in the early 1970s that the Air Force had decided it was switching its workhorse booster from the Thor Agena to the far larger Titan III. The NRL ELINT program—also then known as Program C of the National Reconnaissance Office—depended on the Air Force-based Program A of NRO for the boosters, and Program A's team was designing larger satellites that required larger boosters. "We figured if we [had] to pick up the additional

cost of these expensive boosters, that could kill our program,” Wilhelm recalled later. And then, in a particularly consequential application of his problem-solving skills, Wilhelm arranged for the lab to gain access to Atlas ICBM boosters that were getting mothballed in the California desert as they gave way to next-generation Titan ICBM boosters.

“The Atlas could not get into orbit by itself, but it could get close,” Wilhelm knew, but he also had a solution in mind. “By stacking another solid rocket on top of it, it could reach orbital altitudes. I was an electrical engineer, and I did not understand too much about orbitology in those days. But I taught myself.”³³

With proper modifications—most notably in the form of “a very small rocket within the satellite itself” that could refine the satellite’s orbit once the Atlas booster had brought it there—Wilhelm saw it could do the job of positioning the ELINT satellites where they needed to be, and at a bargain price. The price tag for achieving the proper orbit would be \$6 million with the Atlas, rather the \$25 million it would take with the Titan III. This would save \$19 million 1970s dollars on every launch.

In its way, it was as big and bold an idea as Mayo’s vision to loft into orbit a radar-detecting sensor originally designed for submarines. Indeed, the idea of successfully using obsolete ICBMs in a cost-saving coup for a pivotal national reconnaissance capability seemed outlandish to the NRO leadership at the Pentagon.³⁴ “My boss [Lorenzen] and I went to ‘4C1000,’ what we called the NRO offices in the Pentagon at the time,” Wilhelm recalled. “I got up in front of the NRO people and started describing the concept. General Bradburn³⁵ jumped and said, ‘No, no. That is not going to work! What in the heck are you talking about! No way! You can’t make orbit with that vehicle.’ I said, ‘Sir, I think we can.’ He said, ‘Well, you’re not an expert! I want my people to check this out! This briefing is over!’”³⁶ By the next week, General Bradburn’s own experts had confirmed that Wilhelm’s plan should work. The fire-sale Atlas rockets became workhorse boosters for the NRL engineers for nearly 15 years. And the concept of attaching a small rocket to the satellite structure itself, particularly in combination with the Multiple Satellite Dispenser (MSD)—another Wilhelm brainchild—was replicated or modified several times as Wilhelm’s team designed, built, and transferred to industry partners subsequent generations of orbiting ELINT systems.

The Atlas/MSD innovation proved to be a lasting and expanding success. It also led to a career highlight for Wilhelm. In 1976, Wernher von Braun, one of the most famous names of the Space Age and the archetypal “rocket scientist,” visited the space technology operation that Wilhelm was running.³⁷ For Wilhelm, it was one of the greatest moments of his life. He recalls one particular episode this way: “We took him on a tour of the whole laboratory, and I took him into the clean room where we had some of the micro-thrusters. I showed him how, over the years, we had managed to make them smaller and smaller. He was sitting at the microscope, adjusting it and shaking his head. He said, ‘I can’t get over this! My whole career I have tried to make



Space Giants. In 1976, the most famous rocket engineer of the era, Wernher von Braun, visited NRL. From left to right is Wilhelm, von Braun, another non-NRL visitor, and James Winkler.

the rocket bigger and bigger, and you guys are making things smaller and smaller!” In a capping moment, the two giants of space technology traded autographs.³⁸

Neither Wilhelm, nor the space technology tradition at NRL, would ever become household names as did Wernher von Braun and NASA. But within the deliberately and necessarily lower profile of the military and classified side of the U.S. space program, Wilhelm and his NRL space technology colleagues would become a go-to team in the government when it came to national needs in space. When Lorenzen retired in 1973, and with an additional reshuffling within the lab’s organizational structure that morphed the Satellite Techniques Branch into the Spacecraft Technology Center (Code 7040), more of the lab’s space-based research and development consolidated under Wilhelm’s leadership. It also placed Wilhelm only one tier away from the level of the Space Science and Technology directorate’s Associate Director of Research, a position that reported directly to NRL’s civilian Director of Research, at the time Dr. Alan Berman.

In 1981, another administrative shift elevated the Spacecraft Technology Center to a full-blown division: the Space Systems Division. “What the lab was trying to drive toward was basically to get all of the space work into one organization,” Wilhelm explained.³⁹ And there seemed to be ever more to pack in. By 1984, Wilhelm found himself in charge of eight branches: Electrical Systems and Spacecraft Integration, Terrestrial Systems, Mechanical Systems, Systems Engineering and Analysis, Digital Systems, Radio Frequency and Optical, Space Applications, and Space Sensing Applications. Wilhelm was on the verge of getting overwhelmed. After this reorganization had unfolded, “it was very difficult for me to interface adequately with that many people,” Wilhelm conceded. “I tended to focus more attention on certain groups than on others. I just couldn’t cover that many bases.”⁴⁰

That situation was rectified in 1986 during the next major reorganization with the establishment of the Naval Center for Space Technology, NCST, which was the

result of a revamped Navy Space Policy put forward in the first half of the 1980s by the Secretary of the Navy, Dr. John Lehman, and other top-echelon planners. As mentioned in Chapter Twelve, NCST initially was organized into three departments. Wilhelm, director of the new NCST, assigned three senior engineers and confidants to head them—Robert Eisenhauer took the helm of the Space Systems Development Department, Robert Beal took the directorship of the Spacecraft Engineering Department, and Lee Hammarstrom took on leadership of the Space Systems Technology Department, which in 1992 would merge into the other two departments.⁴¹

The reorganization brought with it what almost proved to be a deal breaker for Wilhelm. The lab's Director of Research at the time, Dr. Timothy Coffey, wanted Wilhelm, who was now an equivalent of the lab's other Associate Directors of Research (ADORs), to relocate his office to the lab's main administrative building, Building 43. It was a move that would place Wilhelm's office next to the other ADORs, but Wilhelm also knew such a move would have been anathema to his own penchant to remain close to, in his words, "the technical scope of the program."⁴² Wilhelm had some leverage here. After all, the operation he had been overseeing had a record of bringing money and clout to the lab, and of producing highly valued intelligence, surveillance, and reconnaissance capabilities for the country. He was able to work out a compromise. His colleague, Fred Hellrich, became an administrative deputy and he agreed to occupy an office in Building 43. Meanwhile, Wilhelm continued to focus on the technical portfolio in Building A59 and a few other R&D locations at the lab and at field sites, such as the satellite control facility at Blossom Point. This arrangement spared Wilhelm additional administrative tasks that would have demanded much of his time.

The establishment of a place like NCST within the Navy took longer than it should have, according to Wilhelm. After all, he said, "the Navy's role is basically a worldwide one covering three-quarters of the Earth, and the Navy is spread out so far that when you think of how the Navy can conduct its mission, I think that you would very quickly be led to the view that space-based systems can really fill the role and solve some of the Navy's problems, like probably nothing else can."⁴³ With the opening of NCST in 1986, Wilhelm added, he had hoped the Navy finally would make the larger commitment to space he thought it needed to. At the same time, he also understood the delay because he knew the Navy's more natural and intuitive concerns were assets like ships and submarines, not satellites and C4I equipment.

At about the same time that NCST was established, NRL Director of Research Coffey was pushing for a change of mind-set by the space technologists at the lab. It had been clear for years already that the survival of the group could not ride indefinitely on the NRO's classified programs—nor on the new money that was coming in during the 1980s with the Strategic Defense Initiative, first for the LACE mission and then for Clementine. In response, Wilhelm's staff became more intentional about partnering with many of the lab's other 16 major R&D divisions on projects ranging

from new superconducting materials for next-generation sensors to theoretical studies of large-scale solar energy harvesting from space.⁴⁴

It was a partnering practice that capitalized on one the lab's greatest assets—a multidisciplinary nature that made it possible for researchers with different skills to find one another to solve problems that each on his or her own could not solve. Said Wilhelm: “Just working here at NRL, I can't think of how many times, when we had a problem in the satellites, I could just walk basically across the street to another division and there was an expert over there—whether it be a metallurgist or a chemist or whatever—who could help solve a problem for us. The fact that this laboratory is so broadly based has been a real asset for our space technology mission.”⁴⁵

Under the entrepreneurial leadership of Eisenhower, then head of NCST's Space Systems Development Department, NCST also in the 1980s began expanding its efforts and accomplishments in the myriad components and systems that were underneath the “orbiting peripherals,” the satellites. This led to technology developments that eked ever more tactical value for warfighters out of the national intelligence assets in orbit. NCST's C4I portfolio expanded as the satellite work began to wane, at least compared to the previous two decades.

When the Air Force announced in the 1970s that it was shifting its booster from the Thorad Agena booster for NRL's Poppy ELINT satellite program to the larger and far more expensive Titan III, Wilhelm responded with his innovative idea to adapt the less expensive Atlas F ICBMs, which the country was phasing out of their original nuclear-warhead delivery role, for NRL's space projects. Reducing the cost of getting mass, including satellites, into orbit had been a long-time theme for Wilhelm and, for that matter, the space community in general.

That is why the continuing trend by the Air Force toward even bigger rockets during the 1980s primed Wilhelm into considering another approach to reducing launch costs. It would grow into a major NCST project between 1988 and 1991. Known in its long form as Sea Launch and Recovery, SEALAR was reminiscent of a World War II scheme by the German rocket engineers in Peenemünde who had designed a version of their V-2 ballistic missile that could strike the United States. Their idea had been to insert a V-2 inside large waterproof capsules, which a U-boat would then tow across the ocean to within striking distance of U.S. cities. Once there, ballast tanks in the capsule would be flooded to render the capsule vertical. Then the U-boat crew would set the missile's guidance system and launch the weapon. German war engineers built a launch container for this variant of the V-2 before the war ended, but they never conducted a live fire test.⁴⁶

In addition to reducing launch costs, the SEALAR project also was about liberating the Navy from dependence on the Air Force for launch services. “Let's say that in the future we need a booster that is much bigger than the Saturn 5,” Wilhelm said in an interview, referring to the massive booster made famous during the Apollo missions. “It really starts to boggle your mind on how you can handle anything of that size on the

land without building facilities that would make the pyramids look like child's play."⁴⁷

"If it turns out that the best way to actually get access to space is by use of the ocean itself, sea launch and recovery could be the answer to our space transportation needs," he continued. "In that case, the Navy would not only have 'more to gain' from space, but would also have 'more to contribute'—a sort of poetic justice."⁴⁸

The SEALAR program began almost by chance at the end of a visit Wilhelm made in 1988 to an Admiral at the Pentagon. As he was leaving, another Navy officer handed him a proposal about the concept of launching and recovering rockets at sea by Robert Truax, a former Navy Captain, who managed rocket design programs for the Navy until retiring in 1959. In 1966, with an interest in furthering his own life-long quest to reduce launch costs, he founded his own rocket engineering company, Truax Engineering, Inc. (TEI). "I found it fascinating," Wilhelm said of the proposal, "and I contacted Truax."⁴⁹ Wilhelm also got in touch with the Chief of Naval Research at the time, John R. "Smoke" Wilson (USN Rear Admiral, retired). Recalled Wilhelm, "He saw this as a way for the Navy to really use all of Naval capability to put things into orbit. All you had to do was a little engineering,"⁵⁰ Wilhelm said with deliberate understatement.

Later in 1988, NCST sent out a call for bidders with the task of collaborating on a project to design and build a two-stage, sea-launched, recoverable launch system that could put 10,000 pounds into low Earth orbit at minimum cost. As it turned out, TEI won the contract.⁵¹

The initial tack Truax pushed was to build the rockets using an especially strong type of steel, maraging steel. Truax was convinced that despite its tendency to become brittle under stress, this type of steel would withstand a hit on the ocean surface after its boosting role had been completed. Initial tests using 6- to 8-inch-diameter scale models shot into a water tank at another naval research facility justified going to more involved "drop tests" using helicopters. In a series of three such tests in Monterey Bay, California, larger models were dropped into the ocean near the Naval Postgraduate School from an altitude high enough that the models would reach the same terminal velocity they would have had they fallen from the edge of space. Wilhelm points out that the team was only able to carry out the tests after assuring Greenpeace activists that the drops would not threaten sea lions in the area.⁵²

During the first drop, the vehicle wobbled unstably and was flattened by the impact, Wilhelm recalled.⁵³ For the second test, Wilhelm called on his engineers in Building A59 to increase the vehicle's stability by heavying it up, enlarging its fins, and building in a larger separation between the center of pressure and the center of mass. The test went well. But during the third drop test, the vehicle landed on the side of a wave and, says Wilhelm, "got beat up pretty bad." The data was in: either the design or the maraging steel was not up to the job at hand, that is, to render a booster rocket recoverable after it had fallen into the sea.



Booster Redo. Shown here is the SEALAR project logo along with images from a helicopter drop test in Monterey and a static firing from a barge that served as a research platform.



It was time for another tack. The collaborators dubbed the new test vehicle the X-3, which included four steerable LR101 rocket engines built by Rocketdyne. It was a single-stage, suborbital test vehicle fueled by a liquid oxygen (LOX)/kerosene combination. The booster included a valve system that retained enough internal pressure once the fuel was exhausted to give the now empty structure enough integrity to survive an ocean landing. After sufficient testing of the rocket components, Wilhelm said, a big next step would be to try a water launch in a so-called spar-buoy, a particularly stable type of buoy that is long and floats upright when its bottom is filled with water. It is reminiscent of the V-2 tow-and-launch vessel that German engineers had envisioned during World War II.

With an eye on keeping development costs down for the static firing tests of the liquid fuel main vehicle, which was the natural next step, Truax recommended that the collaboration acquire a surplus Navy barge. To pull that off, Wilhelm assigned John Schmidt, who had earned a reputation for being able to secure materials and means for a variety of NCST projects. “He could get almost anything you want,” Wilhelm recalled. In addition to acquiring a supply of Rocketdyne’s LR101 rocket engines, Schmidt got hold of a Yard Fleet Navy Barge that was in San Diego. Equipped with lathes, band saws, and other tools, the Navy had used the barge as “a floating schoolyard for training machinists,” Wilhelm said. For the SEALAR project, it would become a platform for conducting static firing tests of 10-foot models of the main vehicle. The full-size rocket design would rise to 25 feet.

After overcoming glitches, including damage to the barge as a tug boat hauled it overzealously to waters off of Redwood City near the San Francisco Bay, which is where TEI was located, the momentum on the SEALAR program began to build. Once the barge was in place and fitted with spherical fuel tanks for the liquid oxygen and kerosene and the plumbing to pressurize the test rockets, the team conducted

a number of static tests—with the rocket exhaust shooting into and spectacularly vaporizing the ocean water—to determine the optimal fuel pressures in the rockets' tanks. The engineering phase of the SEALAR project seemed to be entering a smooth gait.

It was looking promising enough in 1990 that the Senate Armed Services Committee in July upped the Navy's 1991 SEALAR budget request by 900 percent (from \$2.5 million to \$22 million), and called for a competition between SEALAR and the Air Force's Advanced Launch System (ALS) program. The Committee's report on the fiscal year 1991 defense budget concluded that SEALAR indeed could lower launch costs and increase operational responsiveness for a fraction of the cost of the Air Force's advanced launch system. The report characterized the ALS development program as being entirely unrealistic.⁵⁴ The ALS program featured a booster three times larger than the already massive Titan IV.⁵⁵

For NCST and TEI this surely was good news. The SEALAR program suddenly had become a significant component of NCST's overall R&D portfolio, perhaps one-third by Wilhelm's estimate.⁵⁶ But it didn't take long for Wilhelm to receive a rude reminder of how precarious is the game of rocket engineering, which NRL had gotten out of decades earlier after the Vanguard program transferred to NASA when the civilian agency was established in 1958. Back in Washington, while on a golf outing with coworkers, Wilhelm learned via a bad-news phone call from colleagues on site at the barge in California that the liquid oxygen tank on a test vehicle had violently split open during a test involving repeated pressurization cycles.

This convinced Wilhelm that Truax's choice of maraging steel, which NRL's own materials experts thought was a bad idea from the start, would have to give way to the traditional rocket material, aluminum, even though that would set the engineering clock back considerably. He set his engineers in Building A59 on the task of fabricating the aluminum version of the flight demonstrator and by the end of 1991 they were making quick progress toward a vehicle that would be ready for flight tests.⁵⁷

But there was an even more perilous development in the overall SEALAR context to contend with: the sponsorship for SEALAR had shifted from the Office of Naval Research, headed by the enthusiastic Chief of Naval Research (CNR), Smoke Wilson, to an office within the Secretary of the Navy, which was none too keen on the project. When this failure occurred, Navy leadership pulled its support.

"SEALAR was a sobering lesson," commented Timothy Coffey, a plasma scientist who was NRL's civilian Director of Research during the SEALAR program. Even though Wilhelm and his collaborators managed to get the CNR to commit some \$15 million to the program over several years, it was not sufficient for the program to succeed, Coffey said, adding that there were a lot of politics involved. For one thing, not everyone in government, particularly the Air Force, wanted the Navy to have its own launch capability. And the project was controversial within NRL too because, Coffey noted, it was not clear where the money for a sustained SEALAR effort would come

from.⁵⁷ The Senate Armed Services Committee also urged NCST to secure funding beyond the 1991 government outlay.⁵⁸

Even so, Wilhelm remained convinced that some SEALAR-like design could dramatically reduce launch costs, so he maintained a mostly conceptual level of SEALAR engineering at NCST. With the hazards of liquid fuel in mind, the team developed designs for hybrid motors in which liquid oxidizer would flow through wagonwheel-shaped cores of solid propellant. As with the Space Shuttles, these would strap onto a larger central liquid oxygen tank on the overall vehicle. The hybrid motors would constitute the first and second stages of the ascent before giving away to the liquid-oxygen-based third stage. In the interest of realism, the NCST designers abandoned the requirement that all parts of the booster be recoverable. Instead, they focused on systems in which only the central core of the vehicle would need to make a soft landing. One design included parafoils that would steer the vehicle into a net stretched over a barge. Another featured a “rotary decelerator,” or a helicopter-like rotor that would develop lift to counter the speed of descent.

“I had quite a team working on this,” Wilhelm said, including contractors. With the help of Lee Hammarstrom, who during his career worked both at NRL and the National Reconnaissance Office, Wilhelm managed to get NRO to commission a study—dubbed Basic Launch Understanding (BLUE)—on the challenge of lowering launch costs. This spawned what appeared to Wilhelm as a resurgence of interest in the SEALAR concept. “I was pretty well convinced that we were going to move ahead and have a nice program,” he said.⁵⁹

Then, once again, the axe came down on the program. As Wilhelm explained it, there were two reasons. One was that Hammarstrom, a friend of NCST within NRO, had to take time away from NRO for other necessities. The other, Wilhelm claims, was that a high-level Air Force officer at NRO became convinced that NCST actually was onto a good idea and relayed that sentiment to the Space and Missile Systems Center, the Air Force’s space headquarters in Los Angeles.

“As soon as they found out we were doing something good,” Wilhelm said, they killed BLUE, which amounted to the follow-on project to SEALAR. The Air Force told NRO that “it was getting out of its lane,” that the building of rockets was Air Force business, not NRO business. “We got word from NRO that the program was dead” in early 1995, Wilhelm stated.

The same year that NCST stopped its SEALAR efforts, a collaboration called Sea Launch began between RSC Energia, Russia’s largest manager of spaceflight projects with roots going back to the beginning of the Space Age; the Boeing Company in the United States; and several other partners. Since its first demonstration launch in 1999 from an enormous self-propelled platform (a modified oil rig), Sea Launch has executed a few dozen launch operations with Russian-built Zenit-3SL vehicles from oceanic sites for a variety of customers. Four of the launches have failed, including one in early 2013. And the pathbreaking commercial space firm SpaceX, as well as

others in this nascent industry, have begun conducting their own initial experiments with boosters recoverable at sea.

Wilhelm always has had multiple balls in the air. Even as on-again/off-again SEALAR was approaching its end game, he and his NCST brethren were in the business of designing, building, and operating payloads. In one of his greatest displays of the right stuff that it takes to be in the space business, Wilhelm in early 1994 almost singlehandedly saved an innovative sub-\$100 million space technology mission—Clementine, that is—from what otherwise would have been a total failure. The problem resided in a rechargeable, nickel-hydrogen battery system that Wilhelm had some experience with during the Timation program of the 1960s and 1970s. Recharging the battery depended on solar cells that had to be pointed correctly with respect to the sun.

“The satellite got into trouble and it wasn’t oriented properly initially and so we weren’t getting much charge,” Wilhelm recounted.⁶⁰ As a result, every time the team tried to turn the satellite systems on, a sensor registered an undervoltage and the satellite would automatically turn off. There were hints from telemetry signals (associated with the gas pressure inside the battery, a surrogate for the charge level) indicating that the battery was low, not dead. Wilhelm knew this meant there was some hope of reviving it.

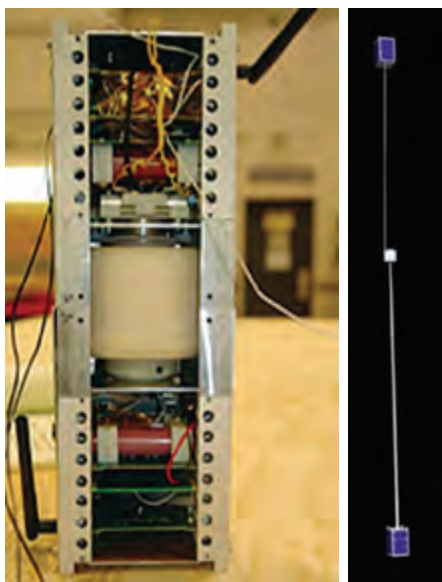
This is where Wilhelm’s right stuff kicked in. He recalled it this way: “So I said let’s stop commanding it; just leave it alone and let it get charged back up. And we did that for 24 hours. We didn’t send a damn command to the satellite. And then we finally crossed our fingers and sent a command and the battery was now up and was strong enough that we could reorient [the spacecraft] and we were off and had a very successful mission.” The gas gauge, which engineers at NRL had long ago included in the battery design on the Timation program, saved the day, Wilhelm said, noting how small engineering innovations years ago could be pivotal for a future mission’s success.⁶¹ This sort of leveraging of knowledge, expertise, and technology can only occur in a long-term context such as a space technology tradition that NRL had been building since 1946, he noted.

On September 27, 2011, Wilhelm and his 275 colleagues celebrated the lab’s 100th payload launch with the successful placement of TacSat-4 into orbit from a launchpad in Kodiak, Alaska. It was a return to the small and quick-turnaround mentality of the early days a half-century earlier. The prospects for a lot more actual satellite building had not been good for some years already, though NCST in the teen years of the new millennium was keeping a hand in a leading-edge movement toward so-called microsattellites (sometimes called nanosatellites), or cubesats, in which space platforms of greater or lesser complexity are built up from modules that could fit inside a box of facial tissues. Cubesats at various stages of design and completion could be found in several NCST locations, among them Building A59 and at the ground station in Blossom Point, Maryland. In the same time frame, there were other

major and exciting projects in the works, including the Microwave Imager Sounder whose ultimate fate remains uncertain.

Wilhelm, NCST, and its predecessor organizations within NRL have been there before. Near death has been a routine challenge that they have overcome each and every time. Wilhelm has never been much of a worrier; he is more of a doer, a planner, and a problem solver. High on his mind as the new millennium's second decade unfolds is the growing danger that the massive and still growing amount of orbiting detritus of the Space Age could become that which puts the brakes on further progress in space.

One mention of TEPCE, for example, which stands for Tether Electrodynamic Propulsion Cubesat Experiment, and Wilhelm lights up with an expression that surely is just today's version of what he looked like when he worked on his first satellite transmitters back in 1959 and 1960. With roots in NCST's TiPS and ATEEx projects, TEPCE consists primarily of two cubesats connected with a one-kilometer-long conductive tether. As it moves through the thin, electrically charged plasma that infiltrates near-



Charge Up. Building on earlier work with two-part payloads connected by a tether, Peter Wilhelm and a team of NCST engineers developed the Tether Electrodynamic Propulsion Cubesat Experiment, TEPCE, to test the concept of generating electricity for propulsion as a conductive tether moves through electrically charged plasma in near-Earth space.

Earth space, an electrical current, which is generated with solar cells, is supposed to start running in the tether, providing power for an electric propulsion system so that the spacecraft can maneuver without the need for canisters of fuel or gas.

With such spacecraft, Wilhelm projected, you “could go collect a piece of debris, probably with a robot attachment, drag this thing down to a lower altitude, let it go, and let it burn up and then boost yourself back up and just keep doing that ... You would probably envision a fleet of these things up there, like little garbage trucks going around grabbing stuff.”⁶²

He is as passionate about this vision as any he has had during his more than half-century ride with the entire Space Age. Said Wilhelm, “To me it is a game changer, and I would just like to be a part of seeing that technology, which has never been done before, get used and help solve this damn debris problem that we have made for ourselves. We’ve really screwed space up in the 50 years we’ve been at it.”⁶³

This is perhaps his biggest lament, his most lasting gripe, in an otherwise ebullient view of his, NRL’s, and NCST’s roles in the Space Age and the U.S. space program. In 2012, while in his late seventies and still running NCST like a much younger man would, he knew that the time was not so far when he finally would hand over the reins. Said Wilhelm during a video interview about NRL’s roles in the advent of the Global Positioning System, “if my career ended tomorrow, I would have to say it was a good satisfying one.” Two years later, in his succinct announcement that he had decided to retire, he reiterated that assessment: “This has been the best career anyone could have asked for.” When Wilhelm retired, Chris Dwyer, head of NCST’s Space Systems Development Department, took the baton from him to serve as Acting Director, a role he alternated with John Schaub, then head of NCST’s Spacecraft Engineering Department. In 2016, Schaub was named as the second director of NCST. As NCST’s new leadership takes the organization forward, Wilhelm’s legacy will continue to contribute as his numerous conceptual and engineering innovations will keep unfolding in the ongoing histories of NRL, NCST, and the Space Age.

¹ Robert A. McDonald (ed.), *Beyond Expectations—Building an American National Reconnaissance Capability: Recollections of the Pioneers and Founders of National Reconnaissance* (Bethesda, MD: National Reconnaissance Office and the American Society of Photogrammetry and Remote Sensing, 2002), p. 160.

² Peter Wilhelm, interview with TV crew and author, February 16, 2012; Peter Wilhelm, interview with NRL Historian Leo Slater, August 7, 2009.

³ Wilhelm, interview with Slater, August 7, 2009.

⁴ Wilhelm, interview with Slater, August 7, 2009, p. 4.

⁵ Wilhelm, interview with Slater, August 7, 2009.

⁶ Wilhelm, interview with Slater, August 7, 2009, p. 6.

⁷ Wilhelm, interview with Slater, August 7, 2009, p. 7.

⁸ It would be more accurate to refer to him as a returnee in that any Vanguard staff that wanted to stay at NRL actually had to reapply for an NRL job after first officially transferring to NASA as part of the law that established the new civilian space agency.

⁹ Peter Wilhelm, interview with author, February 16, 2013.

¹⁰ Wilhelm, interview with author, February 16, 2013.

¹¹ McDonald, *Beyond Expectations*, p. 155

¹² Wilhelm, interview with Slater, August 7, 2009, p. 10.

¹³ Wilhelm, interview with author, February 16, 2013, p. 7.

¹⁴ Peter Wilhelm, interview with NRL Historian David van Keuren and Archivist Dean Bundy, November 19, 1987, p. 7.

¹⁵ Wilhelm, interview with van Keuren and archivist Bundy, November 19, 1987.

¹⁶ Wilhelm, interview with Slater, August 7, 2009, p. 11.

¹⁷ Wilhelm, interview with Slater, August 7, 2009, p. 11.

- ¹⁸ Wilhelm, interview with Slater, August 7, 2009, p. 11.
- ¹⁹ More properly, it was the other way around. SOLRAD 1 was stowaway on the classified program, which was the primary mission.
- ²⁰ Wilhelm, interview with TV crew and author, February 16, 2013.
- ²¹ Wilhelm, interview with author, February 16, 2013.
- ²² Wilhelm, interview with TV crew and author, February 16, 2013, p. 6.
- ²³ Wilhelm, interview with TV crew and author, February 16, 2013, pp. 13–14.
- ²⁴ Wilhelm, interview with TV crew and author, February 16, 2013, pp. 13–14.
- ²⁵ SOLRAD 4.
- ²⁶ LOFTI 2A.
- ²⁷ Robert A. McDonald and Sharon K. Moreno, *Raising the Periscope... Grab and Poppy: America's Early ELINT Satellites*, (Chantilly, VA: Center for the Study of National Reconnaissance, National Reconnaissance Office, September 2005), p. 19.
- ²⁸ Interestingly, it was one of the first co-directors of the National Reconnaissance Office, Joseph Charyk, who is partly responsible for the NRL-to-COMSAT conduit. Charyk left the NRO in December 1962 to become president of the company.
- ²⁹ Wilhelm, interview with TV crew and author, February 16, 2012, p. 16.
- ³⁰ Wilhelm, interview with Slater, August 7, 2009.
- ³¹ Wilhelm, interview with Slater, August 7, 2009, p. 17.
- ³² Wilhelm, interview with author, February 16, 2013.
- ³³ McDonald, *Beyond Expectations*, pp. 155–162.
- ³⁴ McDonald, *Beyond Expectations*, pp. 155–162.
- ³⁵ General David Bradburn had been involved in the Air Force's leadership in satellite technology since the late 1950s.
- ³⁶ Wilhelm, interview with Slater, August 7, 2009; Wilhelm, interview with author, February 16, 2013.
- ³⁷ James Winkler, "My Career at the Naval Research Laboratory," memoir shared with the author.
- ³⁸ Peter Wilhelm, Patrick W. Binning, and Jay W. Middour (interviewers): An Interview with Peter Wilhelm May 28, 2007 and July 16, 2007, transcribed by Patrick W. Binning.
- ³⁹ Wilhelm, interview with TV crew, February 16, 2013, p. 19.
- ⁴⁰ Wilhelm, interview with TV crew, February 16, 2013, p. 19.
- ⁴¹ For a good schematic of these changes, see <http://ncst-www.nrl.navy.mil/NCSTOrigin/NC-STOrigin2.html>.
- ⁴² Peter Wilhelm, Patrick W. Binning, and Jay W. Middour (interviewers): An Interview with Peter Wilhelm May 28, 2007 and July 16, 2007, transcribed by Patrick W. Binning.
- ⁴³ Peter Wilhelm, Patrick W. Binning, and Jay W. Middour (interviewers): An Interview with Peter Wilhelm May 28, 2007 and July 16, 2007, transcribed by Patrick W. Binning, p. 24.
- ⁴⁴ Timothy Coffey, oral history with David K. van Keuren, October 8, 1998.
- ⁴⁵ Wilhelm, interview with Slater, August 7, 2009.
- ⁴⁶ See, for example, <http://www.uboataces.com/articles-rocket-uboaat.shtml> and <http://www.prinzeugen.com/V2.htm>.
- ⁴⁷ Peter Wilhelm, oral history, October 8, 1998, p. 36.
- ⁴⁸ Wilhelm, oral history, October 8, 1998, pp. 37–38.
- ⁴⁹ Peter Wilhelm, phone interview with author, May 5, 2014.
- ⁵⁰ Wilhelm, phone interview with author, May 5, 2014.
- ⁵¹ John R. London III, "LEO on the Cheap: Methods for Achieving Drastic Reductions in Space Launch Costs," Research Report No. AU-ARI-93-8, Air University Press, Maxwell Air Force Base, Alabama, October 1994, Chapter 9.
- ⁵² Wilhelm, phone interview with author, May 5, 2014.
- ⁵³ Wilhelm, phone interview with author, May 5, 2014.
- ⁵⁴ London, "LEO on the Cheap," 1994, p. 192.

⁵⁵ “Panel Seeks Competition of Navy, USAF Boosters,” *Aviation Week and Space Technology*, July 30, 1990, p. 28.

⁵⁶ Wilhelm, phone interview with author, May 5, 2014.

⁵⁷ Coffey, oral history with van Keuren, 1998, p. 147.

⁵⁸ “Panel Seeks Competition of Navy, USAF Boosters,” 1990.

⁵⁹ Wilhelm, phone interview with author, May 5, 2014.

⁶⁰ Peter Wilhelm, interview with TV crew, “GPS Day 2,” February 15, 2012, pp. 6–8.

⁶¹ Wilhelm, interview with TV crew, “GPS Day 2,” February 15, 2012, pp. 6–8.

⁶² Wilhelm, interview with TV crew, “GPS Day 2,” February 15, 2012, pp. 20–24.

⁶³ Wilhelm, interview with TV crew, “GPS Day 2,” February 15, 2012, pp. 20–24.

BIBLIOGRAPHY, REFERENCES, AND SOURCES

This is the first book-length chronicle of the Naval Research Laboratory's place in the advent and unfolding of the Space Age and, more particularly, in the U.S. Space Program.

For the early chapters, the ones leading up to Project Vanguard, which marks NRL's first program leading to an orbiting payload, I relied heavily on a small collection of scholarly papers and books—including one that I wrote—that focus on NRL and, in some cases, aspects of the lab's history associated with its role in the Space Age. But many of the documentary sources I turned to in order to piece together what sums into a remarkable trajectory in the history of technology in the United States reside in a small set of cabinet drawers at NRL. Residing in these drawers' partitions and folders are many kinds of documents related to NRL's forgettable and unforgettable doings in the advent and unfolding of the Space Age. There are press releases, award citations, memoranda, pamphlets, photographs, newspaper clippings, internal laboratory communications, and all manner of papers that capture some moment, some thought, some ambition along the way. Also important have been a literature of more formal and technical sorts, such as papers published in scientific and engineering journals or by the lab itself as stand-alone lab reports.

By far, the most important source material derives from interviews and discussions with dozens of scientists, engineers, and technicians who have been NRL's "right stuff," to borrow the term author Tom Wolfe used for denoting the particular courage and heroism—or here, that right stuff maps more onto engineering competence and creativity—that it takes to get hardware and humanity into space and to make it useful to warfighters on the ground, on the seas, or in the skies. In some cases, individuals associated with NRL and the Naval Center for Space Technology provided me with documents from their own files, among them resumes and curricula vitae, notes from work and writing projects, and official and unofficial correspondence they had saved. Also invaluable have been a number of oral histories conducted by professional historians and archivists, some of whom have spent parts or all of their careers at NRL.

Of particular value was the one book-length memoir by an NRL space engineer that I know about, this one by James Winkler and written primarily for the benefit of his family. In some ways, my several interviews with Peter Wilhelm, the long-time director of NCST, along with several lengthy oral histories, also amounted to a mem-

oir. Lee Hammarstrom and Bruce Wald, both of who have worn several Department of Defense hats over the years, also generously shared memoirs-in-the-works that helped me clarify several otherwise confusing issues.

The bibliographic listings that follow do not constitute a comprehensive account of the resources I consulted in the preparation of the book. I include extensive end-notes for each chapter that complement the listings here and provide the reader with a more direct way to identify the provenance of a particular passage, claim, or fact.

General and Periodic NRL-produced Information Sources

NRL's *Spectra* magazine highlights the laboratory's advances in the areas of systems, materials science, ocean and atmospheric sciences, and space science.

The *NRL Fact Book* is a reference source for organizational, personnel, and funding information about NRL. It is updated every year.

The *NRL Review*, published annually, is a "snapshot" of the Laboratory, highlighting featured research in selected fields and recognizing NRL personnel for major achievements.

NRL's *Major Facilities* book includes descriptions of NRL facilities. It is organized by directorate and division.

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