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STRENGTHENING NASA'S TECHNOLOGY DEVELOPMENT PROGRAMS

HEARING

BEFORE THE

SUBCOMMITTEE ON SPACE AND AERONAUTICS

COMMITTEE ON SCIENCE AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED ELEVENTH CONGRESS

FIRST SESSION

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CONTENTS

October 22, 2009

Page

Appendix: Answers to Post-Hearing Questions

STRENGTHENING NASA'S TECHNOLOGY DEVELOPMENT PROGRAMS

THURSDAY, OCTOBER 22, 2009

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON SPACE AND AERONAUTICS,
COMMITTEE ON SCIENCE AND TECHNOLOGY,
Washington, DC.

The Subcommittee met, pursuant to call, at 10:07 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Gabrielle Giffords [Chairwoman of the Subcommittee] presiding.

COMMITTEE ON SCIENCE AND TECHNOLOGY
SUBCOMMITTEE ON SPACE & AERONAUTICS
U.S. HOUSE OF REPRESENTATIVES
WASHINGTON, DC 20515

Hearing on

Strengthening NASA's Technology Development Programs

October 22, 2009
10:00 a.m. – 12:00 p.m.
2318 Rayburn House Office Building

WITNESS LIST

Dr. Robert D. Braun
Co-Chair of the Committee to Review the NASA Institute for Advanced Concepts
Aeronautics and Space Engineering Board
National Research Council

Dr. Raymond S. Colladay
Vice Chair of the Committee on the Rationale and Goals of the U.S. Civil Space Program
Aeronautics and Space Engineering Board
National Research Council

Mr. Christopher Scolese
Associate Administrator
National Aeronautics and Space Administration

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HEARING CHARTER

U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE AND TECHNOLOGY
SUBCOMMITTEE ON SPACE AND AERONAUTICS

Strengthening NASA's Technology Development Programs

OCTOBER 22 2009
10 A.M.–NOON
2318 RAYBURN HOUSE OFFICE BUILDING

I. Purpose and Issues:

On October 22, 2009 the Subcommittee on Space and Aeronautics will hold a hearing on the National Aeronautics and Space Administration's (NASA) efforts to define advanced concepts and develop innovative technologies. The hearing will examine (1) the opportunities, challenges, and issues identified in external reviews associated with NASA's analysis of advanced concepts and long-term development of technology; (2) NASA's progress in responding to the provisions in NASA Authorization Acts and recommendations from external reviews associated with technology development; and (3) NASA's efforts to collaborate and coordinate with other Federal agencies on technology development issues. The hearing will focus on the following questions and issues:

- *What are the key findings and recommendations from external critiques of NASA's efforts to conduct advanced concept analysis and long-term technology development? Did they find NASA's existing approach for defining advanced concepts and developing innovative technologies to be effective? What are the budgetary implications of recommended actions?*
- *What results can an agency expect to achieve by conducting a broadly focused long-term program dedicated to stimulating innovation and developing new concepts and capabilities that are not tied to existing requirements? In the absence of a long-term technology program, how can an agency develop and infuse paradigm-shifting technologies that could create opportunities for future missions?*
- *If an advanced technology entity is established in NASA, what key lessons can the agency learn from the Defense Advanced Research Projects Agency's (DARPA) historical evolution in roles, structure, culture, and mission? Is a separate entity required or could its objectives be achieved within the current organizational structure?*
- *Are NASA's flight-system development programs exposed to greater uncertainty and risks when new concepts and technologies are matured within the programs themselves?*
- *Should time horizons be placed on the development of visionary advanced concepts to ensure that projects are not too far out of alignment with the nearer-term horizons of mission programs? How might these time horizons be determined?*
- *Has NASA been responsive to the provisions in authorization legislation directing greater commitment to robust technology research and development initiatives in aeronautics, exploration and space and Earth sciences? Has the agency implemented the recommendations from external reviews for conducting advanced technology development in the agency?*
- *To what extent does NASA coordinate and collaborate with other Federal agencies and departments in planning and conducting long-term aeronautics and space technology development? Have potential overlaps in agency technology research and development activities been identified as a result of such coordination? Has collaboration resulted in greater; synergy among Federal agencies conducting long-term technology development?*

II. Scheduled Witnesses:

- **Dr. Robert D. Braun** Co-Chair of the Committee to Review the NASA Institute for Advanced Concepts Aeronautics and Space Engineering Board National Research Council
- **Dr. Raymond S. Colladay** Vice Chair of the Committee on the Rationale and Goals of the U.S. Civil Space Program Aeronautics and Space Engineering Board National Research Council
- **Mr. Christopher Scolese** Associate Administrator National Aeronautics and Space Administration

III. Overview

Since its creation in 1958, NASA has been one (if the nation's leading technology development engines through its investments in advanced aeronautics and space research and technology. Concepts and advanced technologies such as high-energy cryogenic engines, thermal protection for reusable launch vehicles, electric propulsion, solar and nuclear energy power systems, automation and robotics, and sophisticated sensors enabled landing on the moon, travel to other planets, and monitoring of the Earth's environment. These technologies have transformed the way we live today as evidenced by the ubiquitous presence of and reliance on satellite communications, space-based weather observations, and advanced aviation navigation systems. NASA's technology development efforts and programs have involved several objectives ranging from soliciting visionary advanced techno0gy concepts to developing technologies for mission-specific requirements, advancing instrument capabilities, and qualifying hardware for space flight, among other technology activities to support NASA missions and programs.

The critical importance of technology development was emphasized in the Summary Report of the Review of U.S. Human Space Flight Plans Committee which was tasked to. review the U.S. plans for human spaceflight. The report said:

"The Committee strongly believes it is time for NASA to reassume its crucial role of developing new technologies for space. Today, the alternatives available for exploration systems are severely limited because of the lack of a strategic investment in technology development in past decades. NASA ow has an opportunity to develop a technology roadmap that is aligned with an exploration mission that will last for decades. If appropriately funded, a technology development program would re-engage the minds at American universities, in industry and within NASA. The investments should be designed to increase the capabilities and reduce the costs of future exploration. This will benefit human and robotic exploration, the commercial space community, and other U.S. government users."

With regards to technology development, the summary of key findings included the following observation:

"Technology development for exploration and commercial space: Investment in a well-designed and adequately funded space technology program is critical to enable progress in exploration. Exploration strategies can proceed more readily and economically if the requisite technology has been developed in advance. This investment will also benefit robotic exploration, the U.S. commercial space industry and other U.S. government users."

The need to invest in technology development was also stressed in a recent *Space News* interview (August 24, 2009) of Norman Augustine, Chairman of the Review of U.S. Human Space Flight Plans Committee. Responding to the question of whether he sees a need to reform the way the U.S. government conducts research and development, he responded:

"Developing components of systems during systems development or tests is a very costly way to do that. Far better to develop components and when they've been proven go and develop them and put them into systems. That suggests a need for very strong technology programs, which are particularly vulnerable to budget pressures when they're in the same funding bin as the major programs; so when the major programs gets a cold, the technology program gets pneumonia. We've seen that happen at NASA. So it takes great discipline to continue to invest in technology programs that won't pay off for five, 10, 15 years. But if you don't do it, you end up having component failures that stop you in the midst of system development where the money burn rate is very high."

Another important benefit of technology development lies in its inspirational value. Visionary advanced technology projects have been noted as attracting young talent into NASA and the space program. Regarding that point, the National Research Council (NRC) report on *Fostering Visions for the Future: A Review of the NASA Institute for Advanced Concepts* stated:

> *"One of NASA's roles is to inspire tie public with a spirit of discovery and exploration, and NASA is at its best when it accomplishes this through significant scientific and technical achievement in aeronautic and space. By fostering the identification and development of innovative advanced concepts, and by its actions to advertise the results of its projects to the public at large, NIAC [NASA Institute for Advanced Concepts] served NASA well in support of this inspirational role. A NIAC-like entity facilitates the introduction of valuable products, intellectual and material, into NASA. It broadens the population that can contribute creative ideas and concepts to NASA, a breadth that has generated significant new ideas. These aspects of the success of the previous NIAC form a compelling set of reasons to reinstate an organization with this charter."*

Conversely, *not* having a robust technology development program has been shown to contribute to a greater risk of incorporating immature technologies into flight-system development programs. As was highlighted during the Subcommittee's March 4, 2009 hearing on Cost Management Issues in NASA's Acquisitions and Programs, NASA's attempts to mature technologies during flight-system development programs have resulted in schedule delays and cost 'growth.

Concerns about technology development in NASA have been raised in two recent reports by the NRC. The aforementioned report on the NASA Institute for Advanced Concepts (NIAC) found that the termination in 2007 of the NIAC left the agency without an advanced concepts entity focused at looking beyond today's known needs. As a result, it said that NASA lost its only innovation-focused capability for seeking out fax-reaching, advanced concepts and future capabilities. When NIAC was formed in 1998, its purpose was to fund research concepts and products deemed to be revolutionary and realizable in no fewer than 10 and no more than 40 years. The expectation was that such a program would allow technology risks to be mitigated. This in turn would reduce subsequent development costs and enable new aid more ambitious research goals to be pursued. The NIAC was terminated in Fiscal year 2007, the report said, *"as part of a general elimination of a majority of the ESMD* [Exploration Systems Mission Directorate] *elements not directly aligned with the near-term objectives of the Vision for Exploration."* Many of the projects funded by NIAC were designed for deeper space exploration, or were technologies to be used on Earth, such as an electromagnetic system for formation flying.

In describing the impact of NIAC's termination, the NRC report stated:

> *"The termination of NIAC reflects a larger issue within NASA related to the demise of advanced concepts and technology development programs throughout the agency. To effectively infuse advanced concepts into its future systems, NASA needs to become an organization that values and nurtures the creation and maturation of advanced aeronautics and space concepts. Working for NASA, NIAC helped serve this advanced concepts need for almost 10 years and demonstrated its success in creating a community of innovators focused on advanced concepts that may impact future NASA missions."*

Another NRC report, entitled *America's Future In Space: Aligning The Civil Space Program With National Needs,* recommended that "*NASA should revitalize its advanced technology development program by establishing a DARPA-like organization within NASA as a priority mission area to support preeminent civil, national security (if dual-use), and commercial space programs."* The Defense Advanced Research Projects Agency (DARPA) is the central "high-risk, high reward" research and development organization for the Department of Defense. Established as a agency of the Department of Defense (DOD) in 1958, DARPA funds researchers in industry, universities, government laboratories and elsewhere to conduct high-risk, high-reward research and development projects that will benefit U.S. national security. The agency's research runs the gamut from conducting basic, fundamental scientific investigations in a laboratory setting to building full-scale prototypes of military systems.

The absence of an adequate long-term technology development capability in NASA's science and exploration directorates has been noted by the Congress and addressed in legislation. The NASA Authorization Act of 2008 [P.L. 110–422] encouraged NASA to emphasize long-term technology development. Specific to technology development in exploration, the Act directed the NASA Administrator to carry out a program of long-term exploration-related technology research and development. With regards to missions, the Act directed the Administrator toestablish an intra-Directorate long-term technology development program for space and Earth science within the Science Mission Directorate for the development of new technology.

Today, technology development is conducted by NASA in four primary areas, namely (1) exploration, where the agency develops and matures advanced technology, integrates that technology into prototype systems, and transitions knowledge and technology (some of which requires use of the International Space Station) to the Constellation Program, (2) science, where technology development is conducted in conjunction with individual mission development activities such as the James Webb Space Telescope, (3) aeronautics research, where NASA supports a very broad spectrum of research and development (R&D) activity, and (4) the Innovative Partnerships Program (IPP) which facilitates both technology infusion and technology transfer.

Thus, although technology development at NASA is being performed or sponsored today in several areas, it is not aimed at looking beyond today's known needs and is primarily focused on satisfying the needs of its mission directorates. As a result, NASA is not , pursuing breakthrough technologies that are not explicitly focused on defined requirements. At today's hearing, wee will hear from the Co-Chair and Vice Chair of the two NRC reviews that were previously referenced. We will also hear from NASA's Associate Administrator on what the agency is doing in response to direction and recommendations from authorizing legislation and external reviews as they pertain to technology development.

BACKGOUND INFORMATION

IV. Technology Development Activities in NASA

At the present time, technology development in NASA is being conducted primarily in these areas:

> *Exploration.* The Exploration Systems Mission Directorate's Advanced Capabilities Division (ACD) provides the knowledge, technology, and innovation that will enable current and future exploration missions. ACD is composed of three major programs: the Lunar Precursor Robotic Program (LPRP), Human Research Program (HRP), and the Exploration Technology Development Program (ETDP). Some of that research is performed on the International Space Station. According to NASA, these ACD programs and their projects provide knowledge as a result of ground-based research and technology development, research conducted in space, and observations from robotic flight missions. ACD also develops and matures advanced technology, integrates that technology into pi1ototype systems, and transitions knowledge and technology to the Constellation program. Through its activities, NASA says that ACD provides operational and technical risk mitigation for Constellation Projects.
>
> *Science.* Technology development is conducted in the Science Mission Directorate (SMD) in conjunction with individual mission development activities. For example, NASA took additional time and resources to mature several critical technologies needed by the James Webb Space Telescope (JWST). The JWST contains several innovations, including lightweight optics, a deployable sunshield, and a folding segmented mirror.

Although it is being terminated this fiscal year, SMD has also conducted technology development using the New Millennium Program (NMP) whose objective is to flight-validate revolutionary spacecraft and instrument technologies—a capability that could enhance the science return of future missions, while reducing their cost and risk. Established in 1995, the purpose of NMP was to identify breakthrough spacecraft and instrument technologies, accelerate the infusion of revolutionary technologies into NASA science missions by validating them in the hazardous environment of space, and provide new and lower cost capabilities for Earth and space science missions by reducing the risks to the first users. Validation is needed because, as missions become progressively more difficult, more advanced capabilities are needed, thus opening new, untried technologies to be used for the first time on complex exploration missions. The program consisted of a series of Deep-Space and Earth Orbiting missions that were technology-driven, in contrast to the more traditional science-driven space exploration missions of the past. The first NMP Deep Space mission, DS1, was launched on October 24, 1998. Since that time, NASA successfully validated a solar-powered ion propulsion system, a miniaturized deep space transponder, autonomous operations and navigation software, and other capabilities. NMP funding was eliminated from the FY2009 budget, effectively leading to the program's cancellation.

- *Aeronautics Research.* In contrast to technology development in exploration and science where the recipient of the work is almost exclusively a NASA program or mission, technology development in aeronautics benefits a wide range of entities. The Aeronautics Research Mission directorate (ARMD) supports a very broad spectrum of R&D activity and not merely along the continuum of basic through applied research, development, prototyping, and testing. As was noted by the 2006 NRC report on *Aeronautics Innovation: NASA's Challenges and Opportunities, "ARMD has no institutional responsibility, resources, or capacity to directly implement technologies that the program develops except in unique prototypes or demonstration vehicles. Rather, implementation in public or commercial systems is dependent on a host of other stakeholders." The NRC also noted that "the constraints on NASA's aeronaut1cs program budget have direct and indirect bearings on innovation",* adding further that *"Several participants in the committee's workshops expressed the concern that too many NASA aeronautics projects stopped short of full demonstration of their technical success and utility to users. Experience shows that a potential innovation must be reduced to practice in the complex environment in which it will function before it will be accepted as credible and adopted by the target user community). Such demonstrations in aeronautics often require large expenditures, as has been amply demonstrated by prior NASA and DOD advanced technology demonstrations. The costs of such demonstration programs normally amount to hundreds of millions of dollars. A major part of these demonstration costs is attributable to the systems phenomenon described earlier—unless the technology can be shown to perform as part of the highly integrated system in which it will be used, the prospective user community is likely to discount it."* In NASA's FY 2010 budget requests, the agency proposes to complement its fundamental aeronautics research with systems level research starting with the Environmentally Responsible Aviation (ERA) project.

- *Innovative Partnerships Program.* According to NASA, its Innovative Partnerships Program (IPP) provides the organizational structure for acquiring, maturing, infusing and commercial technology and capabilities for the agency's Mission Directorates, programs and projects through vestments and partnerships with industry, academia, government agencies and National Laboratories. As such, IPP facilitates both technology infusion and technology transfer. NASA says that in addition to leveraging technology investments, dual-use technology-related partnerships, and technology solutions for NASA, IPP enables cost avoidance, and accelerates technology maturation. According to NASA, it uses several elements for doing that, namely Technology Infusion (using the Small Business Innovation Research (SBIR) program, the Small Business Technology Transfer (STTR) program, and the IPP Seed Fund), Innovation Incubator (which includes prize competitions such as Centennial Challenges), and Partnership Development. In its Fiscal Year 2010 budget submission justification, NASA says that in FY 10, "NASA's SBIR/STTR programs will continue to provide high-priority technology needs for NASA with specific technology needs developed in close coordination with NASA's Mission Directorates and other NASA-wide efforts to determine priorities for future technology requirements."

Mr. Christopher Scolese, NASA's Associate Administrator, can provide additional details at the hearing on the agency's technology development initiatives.

V. Authorizing Legislation

NASA's past two authorizations included reference to technology development.

NASA Authorization Act of 2005

P.L. 109–155 [Sec. 421] authorized the NASA Administrator to establish aeronautics research and development initiatives to develop and demonstrate, in a relevant environment, technologies that would enable improvements in several commercial aircraft performance characteristics, namely noise, energy consumption, and emissions. The Act also authorized the Administrator to (1) develop and demonstrate, in a relevant environment, airframe and propulsion technologies to enable efficient, economical overland flight of supersonic civil transport aircraft with no significant impact on the environment; (2) establish rotorcraft initiatives that improve safety, noise, and environmental impact; (3) conduct hypersonics research with the objective of exploring the science and technology of hypersonic flight using air-breathing propulsion concepts, through a mix of theoretical work, basic and applied research, and development of flight research demonstration vehicles; (4) develop revolutionary aeronautical concepts with the intent of pushing technology barriers beyond current subsonic technology; (5) conduct fuel cell-powered aircraft research; and (6) establish a program to conduct Mars aircraft research that would develop and test concepts for an uncrewed aircraft that could operate for sustained periods in the atmosphere of Mars.

NASA Authorization Act of 2008

The NASA Authorization Act of 2008 [P.L. 110-422] emphasized long-team technology development in NASA. Specifically, Sec. 2 of the Act stated that "NASA should make a sustained commitment to a robust long-term technology development activity. Such investments represent the critically important 'seed corn' on which NASA's ability to carry out challenging and productive missions in the future will depend."

Specific to technology development in exploration, the Sec. 405 of the Act stated that a *"robust program of long-term exploration related technology research and development will be essential for the success and sustainability of any enduring initiative of human and robotic exploration of the solar system."* The Act also directed the NASA Administrator to *"carry out a program of long-term exploration-related technology research and development, including such things as in-space propulsion, power systems, life support, and advanced avionics that are not tied to specific flight projects. The program shall have the funding goal of ensuring that the technology research and development can be completed in a timely manner in order to support the safe, successful, and sustainable exploration, of the solar system. In addition, in order to ensure that the broadest range of innovative concepts and technologies are captured, the long-term technology program shall have the goal of having a significant portion of its funding available for external grants and contracts with universities, research institutions, and industry."*

With regards to technology development in science missions, Sec. 501 of the Act directed the Administrator to *"establish an in a-Directorate long-term technology development program for space and Earth science within the Science Mission Directorate for the development of new technology. The program shall be independent of the flight projects under development. NASA shall have a goal of funding the intra-Directorate technology development program at a level of 5 percent of the total Science Mission Directorate annual budget. The program shall be structured to include competitively awarded grants and contracts."*

VI. NRC Reviews of Technology Development in NASA

Advanced technology development at NASA has been analyzed in several reports and surveys conducted by the National Academies' National Research Council.

NRC's Report Fostering Visions for the Future: A Review of the NASA Institute for Advanced Concepts

Congress directed the NRC to conduct a review of the effectiveness of the NASA Institute for Advanced Concepts (NIAC) and to make recommendations concerning the importance of such a program to NASA and to the nation as a whole, including the proper role of NASA and the Federal Government in fostering scientific innovation and creativity and in developing advanced concepts for future systems—NASA formed NIAC in 1998 to provide an independent source of advanced aeronautical and space concepts that could dramatically impact how NASA develops and conducts its missions. The institute was terminated in 2007.

The NRC report, entitled *Fostering Visions for the Future: A Review of the NASA Institute for Advanced Conceits,* was released on August 7, 2009. The Committee to Review the NASA Institute for Advanced Concepts found the NIAC to be effective in developing revolutionary advanced concepts and stated:

> *"Until August 2007, NIAC provided an independent open forum, a high-level point of entry to NASA for an external community of innovators, and an external capability for analysis and definition of advanced aeronautics and space concepts to complement the advanced concept activities conducted within NASA. Throughout its 9-year existence, NIAC inspired an atmosphere for inn, ovation that stretched the imagination and encouraged creativity. Utilizing an open, Web-based environment to conduct solicitations, perform peer review, administer grant awards, and publicize its activities, this small program succeeded in fostering a community of external innovators to investigate advanced concepts that might have a significant impact on future NASA missions in a 10 to 40 year time frame. Funded at approximately $4 million per year, NIAC received a total of $36.2 million in NASA funding, more than 75 percent of which was used directly for grants. NIAC received more than 1300 proposals and awarded 168 grants, for a total of $27.3 million. There were 126 Phase I grants awarded for 6 months of initial study. Upon successful completion of Phase I and based on the continued promise of the advanced concept, 42 Phase II grants were awarded*

by NIAC for 2 years of additional concept maturation. Many NIAC grantees went on to receive additional funding for continued development of their concept from NASA, other government agencies, or private industry. In addition to developing revolutionary advanced concepts, NIAC increased public interest in science and engineering and provided motivation to the nation's youth to study technical subjects."

However, the NRC report said that frequent organizational changes, the last of which placed the NIAC in a mission directorate where mission objectives were not well aligned, preceded termination of the activity:

"Originally conceived as reporting to the agency's chief technologist so that infusion across all NASA enterprises could be assured, NIAC operated in an environment of frequent NASA organizational changes. In 2004, NASA management of NIAC was transferred to the Exploration Systems Mission Directorate, where it was not well aligned with its sponsor's near-term mission objectives. NIAC was terminated in 2007."

In the course of its review, the committee found:

- *"The NIAC program to be effective in achieving its mission and accomplishing its stated goals. At present, there is no NASA organization responsible for solicitation, evaluation, and maturation of advanced concepts, defined as those at technology readiness level (TRL) 1 or 2, or responsible for subsequent infusion of worthy candidate concepts into NASA planning and development activities. Testimony from several sectors confirmed that NASA and the nation must maintain a mechanism to investigate visionary, far-reaching advanced concepts in order to achieve NASA's mission."* [The measurement of Technology Readiness Levels (TRL) is used by NASA and other agencies to assess the maturity of evolving technologies prior to incorporating that technology into a system or subsystem. For example, at the TRL 3 level, active research and development (R&D) is initiated. This must include both analytical studies to set the technology into an appropriate context and laboratory-based studies to physically validate that the analytical predictions are correct. In contrast, a TRL 7 level requires an actual system prototype demonstration in a space environment, a much higher level of maturity.]
- When it was formed, NIAC was to be "managed by a high-level agency executive concerned with the objectives and needs of all NASA enterprises and missions. The committee found that NIAC was most successful as a program with cross-cutting applicability to NASA's enterprises and missions. When it was transferred to a mission-specific directorate, NIAC lost its alignment with sponsor objectives and priorities."
- *"While NIAC's internet-based technical review and management processes were found to be effective and should be continued in NIAC2 [the NRC's characterization of a follow-on effort], the committee found a few policies that may have hastened NIAC's demise. Key among these was (1) the complete focus on revolutionary advanced concepts and (2) the exclusion of NASA personnel from participation in NIAC awards or research teams. NIAC's focus on revolutionary advanced concepts with a time horizon of 10 to 40 years in the future often put its projects too far out of alignment with the nearer-term 1orizons of the NASA mission directorates, thereby diminishing the potential for infusion into NASA mission plans."*
- *"NIAC was formed to provide an independent, open forum for the external analysis and definition of space and aeronautics advanced concepts to complement the advanced concepts activities conducted within NASA; hence, NIAC solicitations were closed to NASA participants. NIAC was formed at a time when there was adequate funding for development of novel, long-term ideas internal to NASA. As internal funding for advanced concepts and technology diminished or became more focused on flight-system development am(operations, the cultural disconnect between the development activities internal and external to the agency grew, and transitioning of NIAC concepts to the NASA miss-on directorates became more difficult."*
- *"That 14 NIAC Phase I and Phase II projects, which were awarded $7 million by NIAC, received an additional $23.8 million in funding from a wide range of organizations, demonstrating the significance of the nation's investment in NIAC's advanced concepts. NIAC matured 12 of the 42 Phase II advanced concepts (29 percent), as measured by receipt of post-NIAC funding; 9 of them (21 percent) received post-NIAC funding from NASA itself. The committee also found that three NIAC Phase II efforts (7 percent of the Phase II awards) ap-*

pear to have impacted NASA's long-term plans, and two of these efforts have either already been incorporated or are currently under consideration by the NRC Astronomy and Astrophysics Decadal Survey as future NASA missions. In addition, the committee received much testimony that the potential for receipt of a NIAC Phase III award is needed to aid the transition of the most highly promising projects."

- *"A persistent NIAC challenge was the lack of a NASA interface to receive the hand-off of promising project. "*

The committee recommended that:

- *"NASA should reestablish a NIAC-like entity, referred to in this report as NIAC2, to seek out visionary, far-reaching, advanced concepts with the potential of significant benefit to accomplishing relevant to NASA's charter and to begin the process of maturing these advanced concepts for infusion into NASA's missions."*
- *"NIAC2 should report to the Office of the Administrator, be outside mission directorates, and be chartered to address NASA-wide mission and technology needs. To increase NIAC2's relevance, NASA mission directorates should contribute thematic areas for consideration The committee also recommends that a NIAC2 organization should be funded and administered separately from NASA development programs, mission directorates, and institutional constraints. Future NIAC2 proposal opportunities should continue to be managed and peer-reviewed outside the agency."*
- *"NIAC2 should expand its scope to include concepts that are scientifically and/or technically innovative and have the potential to provide major benefit to a future NASA mission in 10 years and beyond."*
- *"Future NIAC2 proposal opportunities be open to principal investigators or teams both internal and external to NASA."*
- *"Future NIAC2 proposal opportunities include the potential selection of a small number of Phase III "proof of concept" awards for up to $5 million each for 4 years to demonstrate and resolve fundamental feasibility issues and that such awards be selected jointly by NIAC2 and NSA management."*
- *"NASA consider reestablishing an aeronautics and space systems technology development enterprise. Its purpose would be to provide maturation opportunities and agency expertise for visionary, far-reaching concepts and technologies."*
- *"Identification of center technical champions and provision for the technical participation of NASA field center personnel in NIAC2 efforts. Participation of NASA personnel can be expected to increase as NIAC2 projects mature."*

In its concluding remarks, the committee's report stated:

- *"The termination of NIAC reflects a larger issue within NASA related to the demise of advanced concepts and technology development programs throughout the agency. To effectively infuse advanced concepts into its future systems, NASA needs to become an organization that values and nurtures the creation and maturation of advanced aeronautics and space concepts. Working for NASA, NIAC helped serve this advanced concepts need for almost 10 years and demonstrated its success in creating a community of innovators focused on advanced concepts that may impact future NASA missions. NIAC2 can look out for advanced concepts beyond the current development programs. It can work on the edges where requirements are not yet known, focused on what program managers would want if they knew that they needed it. However, this independent organization that nurtures technology push must also be balanced by a meaningful program of technology pull from the mission directorates, running in parallel and focused on nearer-term phased activities. Towards this objective, the committee recommends that NASA consider reestablishing an aeronautics and space systems technology development enterprise. Its purpose would be to provide maturation opportunities and agency expertise for visionary, far-reaching concepts and technologies. NASA's considerations should include implications for the agency's strategic plan, organizations, resource distributions, field center foci, and mission selection process. The technology development approaches used by other Federal agencies can serve as a benchmark in this examination."*

Dr. Robert D. Braun, Co-Chair of the Committee to Review the NASA Institute for Advanced Concepts which produced this report, will be a witness at the hearing and can provide additional details on the committee's review.

NRC's Report America's Future in Space: Aligning the Civil Space Program with National Needs

The NRC recently released a report recommending a series of measures to better align the civil space program with national needs. The report, prepared under the oversight of both the NRC's Space Studies Board and Aeronautics and Space Engineering Board, is entitled *America's Future In Space: Aligning The Civil Space Program With National Needs.* To contribute to realizing national objectives such as *"Providing clean and affordable energy" and "Protecting the environment now and for future generations", the Committee on the Rationale and Goals of the U.S. Civil Space Program* identified four foundational elements it viewed as *"critical to a purposeful, effective, strategic U.S. space program, without which U.S. space efforts will lack robustness, realism, sustainability, and affordability."* These are:

1. *"Coordinated national strategie—implementing national space policy coherently across all civilian agencies in support of national needs and priorities and aligning attention to shared interests of civil and national security space activities.*
2. *A competent technical workforce—sufficient in size, talent, and experience to address difficult and pressing challenges.*
3. *An effectively sized and structured infrastructure—realizing synergy from the public and private sectors and from international partnerships.*
4. *A priority investment in technology and innovation—strengthening and sustaining the U.S. capacity to meet national needs through transformational advances."*

The foundational element citing investment in technology and innovation led to a committee recommendation on advanced space technology. The report recommended that *"NASA should revitalize its advanced technology development program by establishing a DARPA-like organization within NASA as a priority mission area to support preeminent civil, national security (if dual-use), and commercial space programs."*

The Defense Advanced Research Projects Agency is the central "high-risk, high-reward" research and development organization for the Department of Defense. Established as a DOD agency in 1958, DARPA fund researchers in industry, universities, government laboratories and elsewhere to conduct high-risk, high-reward research and development projects that will benefit U.S. national security. The agency's research runs the gamut from conducting basic, fundamental scientific investigations in a laboratory setting to building full-scale prototypes of military systems.

At the Space and Aeronautics Subcommittee's hearing on *External Perspectives on the FY 2010 NASA Budget Request and Related Issues* held on June 18, 2009, Dr. Raymond Colladay, Vice Chair of the committee that authored the report, advocated for a focused, risk reduction technology program in NASA. In his prepared statement, he stated:

> *"Aeronautics is underfunded, but a broad based, innovative advanced space technology development program that is organizationally independent of ongoing hardware development programs is nonexistent. The downward trend started soon after aeronautics and space technology, once logically managed together, were split apart. A decision soon followed to focus technology specifically on major development program needs by moving the resources to mission areas it intended to serve. Predictably, once all technology development was placed with the major development efforts it became near-term oriented as a risk reduction effort back-stopping hardware development. The Aeronautics and Space Engineering Board sponsored study on the Exploration Technology Development Program for Constellation done last year expressed concern on just that point of the need for more emphasis on longer-term research. With budget and schedule pressures as demanding as ever, the situation has not improved. Clearly, there is a need for focused, risk-reduction technology that is defined by explicit mission requirements and funded by the mission office, but it does not fill the need for the agency on a broader level to pursue long-term technology "push" well out in front of requirements and broad in scope supporting civil (not just NASA) and commercial space. An agency that has inspired us with bold missions and spectacular accomplishments needs to be investing in technology that continually seeks to transform state-of-the-art capabilities and enable future missions that some day we may want to do, if we only knew how."*

In his prepared statement, Dr. Colladay called on NASA to revitalize its advanced space technology development program:

"NASA should revitalize advanced space technology development as a priority mission area of the agency. It should engage the best science and engineering talent in the country wherever it resides in universities, industry, NASA centers or other government labs focused on world-class research and innovation and not driven by the need to maintain ten healthy centers. It should support not only future NASA missions, but other government agencies and commercial space. The "customers " for its technology products would be industry, NASA itself; other government agencies like NOAA, and military space where dual-use technology is applicable. Having this broad mandate would make it similar in the breadth of customers served to the NASA role in aeronautics with its heritage in NACA going back almost a century.

The responsibility to provide for this advanced technology base for civil space activities rests with NASA, in partnership with universities, other government agencies, and industry. The "customers " for the products of technology are NASA, NOAA, industry, and military space programs in which multiple-use technology is applicable. Because of budget pressures and institutional priorities, however, NASA has largely abandoned its role in supporting the broad portfolio of civil space applications, and the space technology base has thus been allowed to erode and is now deficient. The former NASA advanced technology development program no longer exists. Most of what remained was moved to the Constellation Program and has become oriented specifically to risk reduction supporting the ongoing internal development program.

To fulfill NASA's broader mandate, an independent advanced technology development effort is required, much like that accomplished by DARPA in the DOD, focused not so much on technology that today's program managers require, but on what future program managers would wish they could have if they knew they needed it, or would want if they knew they could have it. This effort should engage the best science and engineering talent in the country wherever it resides—in universities, industry, NASA centers, or other government laboratories—independent of pressures to sustain competency at the NASA centers. A DARPA-like organization established within NASA should report to NASA's Administrator, be independent of ongoing NASA development programs, and focus on supporting the broad civil space portfolio through the competitive funding of world-class technology and innovation projects at universities, federally funded research and development centers, government research laboratories, and NASA centers."

Dr. Colladay will be a witness at today's hearing and can provide additional details on the committee's review. Furthermore, as a former head of DARPA, he can provide insight into that agency's past activities.

NRC's Report A Constrained Space Exploration Technology Program

In January 2004, President George W. Bush announced the nation's new space policy by issuing the Vision for Space Exploration (VSE), which instructed NASA to *"extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations."* NASA was also directed to *"develop the innovative technologies, knowledge, and infrastructures both to explore and to support decisions about the destinations for human exploration,"* among other objectives. In response to the direction regarding the development of innovative technologies, NASA focused its resources on maturing the technologies necessary for exploration. NASA's Exploration Technology Development Program (ETDP) was implemented to support, develop, and ultimately provide the necessary technologies for the agency's Constellation flight program.

The NRC's *Committee to Review NASA's Exploration Technology Development Program* was asked to perform an independent assessment of NASA's Exploration Technology Development Program (ETDP) and to offer findings and recommendations related to *"the relevance of ETDP research to the objectives of the Vision for Space Exploration, to any gaps in the ETDP research portfolio, and to the quality of ETDP research."*

In its report entitled *A Constrained Space Exploration Technology Program: A Review of NASA's Exploration Technology Development Program* released in 2008, the committee stated it found the ETDP to be making progress toward the stated goals of technology development. However, the committee also found the technology development program to be *"operating within significant constraints that limit its ability to successfully accomplish those goals. The constraints include the still-dynamic nature of the Constellation Program requirements, the constraints imposed by a limited* *budget, the aggressive time-scale of early technology deliverables, and the desire within NASA to fully employ the NASA workforce."*

The report noted the limitations in scope of the technology development program:

> *"Because of the constraints cited above, the ETDP as created by NASA is a supporting technology program very closely coupled to the near-term needs of the Constellation Program. The ETDP is focused on only incremental gains in capability, and it has two programmatic gaps (integration of the human system, and nuclear thermal propulsion). NASA has in effect suspended research in a number of technology areas traditionally within the agency's scope and has in many areas essentially ended support for longer-term technology research traditionally carried out within NASA and with strong university collaboration. These actions could have important consequences for aspects of the VSE beyond the initial, short-duration lunar missions-including an extended human presence on the Moon and human exploration of Mars and beyond."*

The findings in the report associated with advanced technology development included the following:

- *"The range of technologies covered in the 22 ETDP projects will, in principle, enable many of the early endeavors currently imagined in NASA's Exploration Systems Architecture Study architecture, but not the entire VSE. In examining the projects and the scope of the ETDP, the committee found two significant technology gaps and also identified several crosscutting issues that are characteristic of many of the 22 ETDP projects or of the overall management of the ETDP. A fundamental concern that reflects all of these issues is that the ETDP is currently focused on the short-term challenges of the VSE and is addressing the near-term technologies needed to meet these challenges. Although it is clear that much of this focus results from the constraints on the program, the committee is concerned that the short-term approach characteristic of the current ETDP will have long-term consequences and result in compromised long-term decisions. Extensibility to longer lunar missions and to human exploration of Mars is at risk in the current research portfolio."*
- *"The ETDP has become NASA's principal space technology program. It is highly focused and is structured as a supporting technology program to the Constellation Program, designed to advance technologies at TRL 3 and above toward TRL 6.*
- *Because of this shift toward the relatively mature end of the technology investment spectrum, which is very closely coupled to the near-term needs of the Constellation Program, NASA has also in effect suspended research in a number of technology areas traditionally within the agency's scope, and it has in many areas essentially ended support for longer-term (TRL 1–2) technology research. "*
- *"Although the ETDP has a well-conceived process for managing the programmatic risk of its own technology development, the committee found a lack of clarity in the way that the ETDP accounts for the contributions of its technology developments to reducing exploration (i.e., Constellation) program risk to reducing operational and human health risks, and to considering human-design-factor issues in operations."*
- *"While the ETDP has a good administrative process for determining the formal mechanics of technology transfer, it could improve the effectiveness of the human side of the process by reviewing and adopting effective practice in this area, with the objective of developing a methodology of technology transfer from the development project to the flight project that ensures the successful infusion of the technology."*
- *"The ETDP is currently focused on technologies at or above TRL 3, a focus driven by the need to bring together all of the available resources of NASA to reduce nearer-term Constellation mission risk and at the same time reduce potential Constellation Program schedule slippages within the assigned budget profile."*
- *"Most ETDP projects represent incremental gains in capability, which is not inconsistent with the focus on projects at TRL 3 and above. NASA has largely ended investments in longer-term space technologies that will enable later phases of the VSE, allow technology to "support decisions about ... destinations," in the words of the VSE, and in general preserve the technology leadership of the United States. In assessing the balance between near-term and far-*

term technology investments, the committee found that the current balance of the ETDP is too heavily weighted toward near-term investments."

The committee recommended that:

- *"Managers in the Exploration Systems Mission Directorate and Exploration Technology Development Program should review and carefully consider the committee's ratings of the individual ETDP projects and should develop and implement a plan to improve each project to a level that would be rated by a subsequent review as demonstrating "appropriate capabilities and quality, accomplishment, and plan."*
- *Exploration Technology Development Program (ETDP) project managers should clearly identify the interrelationships between human health and human factor risks and requirements on the one hand and technology development on the other and should ensure that those risks and requirements are addressed in their project plans. Each ETDP project manager should be able to show clearly where that project fits within the integrated Exploration Systems Mission Directorate Advanced Capabilities Program (which includes the ETDP, the Lunar Precursor Robotic Program, and the Human Research Program), and this integrated program plan should include all elements necessary to achieve the Vision for Space Exploration.*
- *Exploration Technology Development Program (ETDP) project managers should systematically include representatives of the Human Research Program on the ETDP technology development teams.*
- *The Exploration Technology Development Program should initiate a technology project to evaluate experimentally candidate nuclear thermal rocket (NTR) fuels for materials and thermal characteristics. Using these data, the Exploration Systems Mission Directorate should assess the potential benefit of using an NTR for lunar missions and should continue to assess the impact on Mars missions.*
- *The Exploration Systems Mission Directorate (EMSD) should review its process for the management of technology development to ensure the timely delivery of technologies for seamless integration into its flight programs. In particular, the ESMD should (1) review and incorporate the considerable expertise in the management and transfer of technology in the larger aerospace, government, and industrial communities; (2) strengthen its management approach by, for instance, appointing a program-level system engineer to ensure that requirements are developed, maintained, and validated in a consistent and complete manner across the entire program; and (3) address the following three issues in particular: (a) the need for a careful assessment of the impact of its technologies on human and operational risk, (b) the need for definition and management of technology requirements, and (c) the importance of recognizing the human elements in the eventual effective transfer and infusion of technology.*
- *The Exploration Systems Mission Directorate should identify longer-term technology needs for the wider Vision for Space Exploration (VSE) that cannot be met by the existing projects in the Exploration Technology Development Program (ETDP) portfolio, which are currently at technology readiness level (TRL) 3 or above. To meet longer-term technology needs, the committee recommends that the ETDP seed lower-TRL concepts that target sustainability and extensibility to long-term lunar and Mars missions, thus opening the TRL pipeline, re-engaging the academic community, and beginning to incorporate the innovation in technology development that will be necessary to complete the VSE.*
- *The Exploration Technology Development Program should institute external advisory teams for each project that (I) undertake a serious examination of potential external collaborations and identify those that could enhance project efficiency, (2) conduct peer review of existing internal activities, and (3) participate in a number of significant design reviews for the project.*
- *The Exploration Systems Mission Directorate should implement cooperative research programs that support the Exploration Technology Development Program (ETDP) mission with qualified university, industry, or national laboratory researchers, particularly in low-technology-readiness-level projects. These programs should both support the ETDP mission and develop a pipeline of qualified and inspired future NASA personnel to ensure the long-term sustainability of U.S. leadership in space exploration.*
- *The Exploration Systems Mission Directorate should evaluate its test capabilities and develop a comprehensive overall integrated test and validation plan*

for all Exploration Technology Development Program (ETDP) projects. All ETDP projects should be reviewed for the absence of key tests (ground and/or flight), especially those that are required to advance key technologies to technology readiness level (TRL) 6. Where new facilities or flight tests are required, conceptual designs for the facilities or flight tests should be developed in order to establish plans and resource requirements needed to include the necessary testing in all ETDP projects."

NRC's Report NASA's Beyond Einstein Program: An Architecture for Implementation

NRC released a report in September 2007 entitled *"NASA's Beyond Einstein Program: An Architecture for Implementation."* Prompted by Congress and the Office of Science and Technology Policy, NASA and the Department of Energy asked the committee to assess the five proposed mission concepts for achieving the goals of the Beyond Einstein space-based physics research initiative, and recommend one for first development and launch.

As part of its charge, the committee was tasked with determining the realism of preliminary technology and management plans, and cost estimates of the candidate Beyond Einstein mission set. Five mission areas—Joint Dark Energy Mission, Black Hole Finder Probe, Inflation Probe, and Einstein Great Observatories—comprised 11 mission candidates. Criteria used by the committee included plans for the maturing of critical mission technology, technical performance margins, schedule margins, risk-mitigation plans, and the proposal's estimated costs versus independent probable cost estimates prepared by the committee.

The committee worked with an experienced outside contractor to develop independent cost estimates and a probable cost range for each candidate mission. The probable cost ranges were also compared with those of previous missions of similar scope and complexity. In all cases, the committee found higher costs and longer schedules than those estimated by the mission teams. The committee observed that this is typical of the differences between the estimates developed by mission teams and by independent cost estimators at this early stage of a program. Given the long history of missions comparable to the Beyond Einstein mission candidates, the committee said that it believed that the most realistic cost range for each of these missions is significantly more than the current estimates provided by the research teams.

In discussing its assessment of mission readiness, the committee stressed the importance of technology readiness as a key consideration in the decision to proceed to mission development. The committee said that ideally, mission development should not commence until all new technologies necessary for mission success have reached a certain level of technology readiness. Experience has shown, the committee added, *"that NASA and other missions pay the price when a mission enters development prematurely."*

NRC's Decadal Surveys of Science Missions

The four completed decadal surveys established by the NRC to recommend ground and space-based programs in Science missions for the next decade—in the areas of astronomy and astrophysics, solar and space physics research, solar system exploration, and Earth science research and applications—strongly endorsed the need for technology development to enable future missions.

Astronomy and Astrophysics in the New Millennium

With regard to the importance of investing in technology, this decadal survey, completed in 2001, stated that:

"Technological innovation has often enabled astronomical discovery. Most of the major discoveries listed at the beginning of this chapter were possible only because of the remarkable advances in technology in the past two decades. Continued investment in technology in this decade is required for many of the initiatives recommended in this report."

"It is essential to maintain funding for the planned technology development if NASA is to keep these missions on schedule and within budget. Targeted technology programs involving a joint effort between engineers and scientists will be essential to success in these projects. As noted above, the committee endorses NASA's policy of completing the technological development of a mission prior to starting it."

"Longer-range investments in technology in this decade are needed to enable the major projects in the next decade-and to make them more cost-effective."

The Sun to the Earth—and Beyond: A Decadal Research Strategy in Solar and Space Physics

Completed in 2003, this decadal survey recommended that NASA:

- *"Assign high priority to the development of advanced propulsion and power technologies required for the exploration of the outer planets, the inner and outer heliosphere, and the local interstellar medium. Such technologies include solar sails, space nuclear power systems, and high-efficiency solar arrays. Equally high priority should be given to the development of lower-cost launch vehicles for Explorer-class missions and to the reopening of the radioisotope thermoelectric generator (RTG) production line."*
- *"Continue to give high priority to the development and testing of advanced spacecraft technologies through such programs as the New Millennium Program and its advanced technology program."*
- *"Continue to assign high priority, through its recently established new instrument development programs, to supporting the development of advanced instrumentation for solar and space physics missions and programs."*
- *"Accelerate the development of command-and-control and data acquisition technologies for constellation missions."*

New Frontiers in the Solar System: An Integrated Exploration Strategy

With regards to technology development, this decadal survey, completed in 2003, recommended that NASA:

- *"Commit to significant new investments in advanced technology so that future high-priority flight missions can succeed Unfortunately, erosion has occurred in the level of investment in technology in the past several years. Flight-development costs have increased over projections, and investments in advanced technologies have been redirected to maintain flight-mission development schedules and performance. For most of the history of planetary exploration, large-cost flight missions such as Voyager, Viking, Galileo, and Cassini have carried a large portion of the technology-development burden in their development costs. During the change in the last decade to a larger number of lower-cost flight missions, the consequent loss of technology development by large missions was compensated by adding separate technology-development cost lines to the planetary exploration portfolio, such as X2000 [NASA's X2000 Program was created in 1997 to infuse new technologies that would enable new, lower-cost and higher-performance spacecraft], under an understood policy of "no mission start before its technological time." This mechanism was intended to separate and remove the uncertainties in technological development from early flight-development costs. However, flight-mission costs have been underestimated, and development plans have been too success-oriented, resulting in erosion of technology-development lines by transfer to flight-development costs. This trend needs to be reversed in order to realize the flight missions recommended in this report."*

Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond

Relative to technology development, this decadal survey, completed in 2007, recommended that:

> "U.S. civil space agencies should aggressively pursue technology development that supports the missions recommended" in the survey; "plan for transitions to continue demonstrably useful research observations on a sustained, or operational, basis; and foster innovative space-based concepts. In particular:
>
> - *NASA should increase investment in both mission focused and cross-cutting technology development to decrease technical risk in the recommended missions andpromote cost reduction across multiple missions. Early technology focused investments through extended mission Phase A studies are essential.*
> - *To restore more frequent launch opportunities and to facilitate the demonstration of innovative ideas and higher-risk technologies, NASA should create a new Venture class of low-cost research and application missions (*−100 million to $200 million). These missions should focus on fostering revolutionary innovation and on training future leaders of space-based Earth science and applications.

- *NOAA [National Oceanic and Atmospheric Administration] should increase investment in identifying and facilitating the transition of demonstrably useful research observations to operational use.*

The Venture class of missions, in particular, would replace and be very different from the current ESSP mission line, which is increasingly a competitive means for implementing NASA's strategic missions. Priority would be given to cost-effective, innovative missions rather than those with excessive scientific and technological requirements. The Venture class could include stand-alone missions that use simple, small instruments, spacecraft, and launch vehicles; more complex instruments of opportunity flown on partner spacecraft and launch vehicles; or complex sets of instruments flown on suitable suborbital platforms to address focused sets of scientific questions. These missions could focus on establishing new research avenues or on demonstrating key application-oriented measurements. Key to the success of such a program will be maintaining a steady stream of opportunities for community participation in the development of innovative ideas, which requires that strict schedule and cost guidelines be enforced for the program participants."

NRC's Decadal Survey of Civil Aeronautics

The idea of conducting a decadal survey of aeronautics originated in discussions among NRC's Aeronautics and Space Engineering Board, the Office of Management and Budget, and congressional committees with an interest in civil aviation. As a result, the Congress and NASA requested NRC to undertake a decadal survey of civil aeronautics research and technology (R&T) priorities that would help NASA fulfill its responsibility to preserve U.S. leadership in aeronautics technology. Issued in 2006, the resultant report presented a set of strategic objectives for the next decade of R&T and provided a set of high-priority R&T challenges—characterized by five common themes—for both NASA and non-NASA researchers, and an analysis of key barriers that must be overcome to reach the strategic objectives.

The report encouraged NASA to closely coordinate and cooperate with other public and private organizations to take advantage of advances in cross-cutting technology funded by Federal agencies and private industry and to develop each new technology to a level of readiness that is appropriate for that technology, given that industry's interest in continuing the development of new technologies varies depending on urgency and expected payoff.

Chairwoman GIFFORDS. The hearing will now come to order. Good morning, everyone. I would like to welcome all of our witnesses here today. We look forward to your testimony and are so pleased that you are here with us.

Today is a very busy day on the Hill, and I am going to try to be brief in my opening so that we will have as much time as possible for discussion. However, I think it is important to note right at the outset that based on all of our witnesses' testimony there is an agreement on the importance of a vital and robust technology development program at NASA and a need to revitalize NASA's existing technology development activities.

And I think it is fair to say that all three would likely agree that NASA has been under-investing in technology development in recent years. Given that two of our witnesses represent distinguished committees of the National Academies and the third is one of the most senior officials at NASA, I think those views warrant our close attention.

Yet to some extent our witnesses are preaching to the choir today. This subcommittee has been concerned for some time about the state of NASA's long-term technology programs, and we highlighted the need for action in last year's NASA's Reauthorization Act. To quote finding number ten from that act, "NASA should make a sustained commitment to a robust, long-term technology development activity." Such investments represent critically important seed corn on which NASA's ability to carry out challenging and productive missions in the future will depend.

I would also note that the summary report of the Augustine Panel that has been reviewing NASA's human spaceflight plans also acknowledged the importance of technology development. And I quote from them. "The committee strongly believes it is time for NASA to reassume its critical role for developing new technologies for space."

That is a sentiment on the Augustine Panel which I believe that we all heartedly concur. NASA's technology development activities are critical not just to NASA's future but to the quality of life for all of our citizens and for our Nation's competitiveness.

Discussions of technology development can wind up sounding pretty wonky, so let me be clear why I think NASA's efforts are so important and need to be supported. This is a photograph. Actually, we were having a recent discussion about this photograph. I know that it is available on the NASA website. It is a picture of a standard commercial airplane that I believe really makes a strong point. As you look at it you will see some of the most major systems and technologies from research undertaken or funded by NASA. It is an aircraft that many members of Congress, actually the majority of us, fly every single week to come here to work, and yet I bet very few of them or even members of the public at large recognize that NASA R&D has made this airplane and others possible.

This picture is just one illustration of the impact of NASA's research on our society and our economy. I have no doubt that each of NASA's other enterprises could produce similar examples, and I hope that they will because it is a story that needs to be told time and time again. So I don't think any of the members here today need to be convinced that NASA should pursue a vigorous program of technology development. Rather, we want to explore what it will take to get such a revitalized program in place at the agency.

And in that regard I want to state my strong belief that we don't revitalize technology development at NASA by robbing Peter to pay Paul. That is carving out funding from an already under-funded Constellation program so that the long-term technology program can be augmented. I believe this would be penny wise and pound foolish. You don't fix one under-funded program by taking money from another under-funded program and expect anything good as a result.

In addition, I suspect that there may not be a one-size-fits-all organizational structure for technology development at NASA, but I want to hear from our witnesses on that topic, as I know that each of them have been thinking a lot about this issue.

But it is not just a question of either money or how the organizational deck chairs are arranged. NASA has to be smart and opportunistic in seeking out ways to get its technologies out to the private sector and to other potential government users. That is probably a topic for its own hearing, but perhaps our witnesses here today will have some thoughts on what NASA could possibly do in that regard.

So I look forward to an interesting and informative discussion. I will ask my colleagues today if we can please refrain from asking our NASA witnesses about NASA's response to the Augustine Panel, which is scheduled to be released later today. We know that Mr. Scolese is not going to be able to make a comment at this point, and we will have other opportunities in the future to get NASA's perspective in the next coming weeks.

So with that again, I would like to welcome our witnesses.

[The prepared statement of Chairwoman Giffords follows:]

PREPARED STATEMENT OF CHAIRWOMAN GABRIELLE GIFFORDS

Good morning. I want to welcome each of our witnesses to today's hearing.

We look forward to your testimony.

Today is a very busy day on the Hill, and I will be brief in my opening remarks so that we have as much time as possible for discussion.

However, I think it's important to note right at the outset that, based on their written testimony, all three of our witnesses agree on the importance of a vital and robust technology development program at NASA, and the need to revitalize NASA's existing technology development activities.

And I think it is fair to say that all three would likely agree that NASA has been under-investing in technology development in recent years.

Given that two of our witnesses represent distinguished committees of the National Academies, and the third is one of the most senior officials at NASA, I think those views warrant our close attention.

Yet, to some extent, our witnesses are "preaching to the choir" today.

This Subcommittee has been concerned for some time about the state of NASA's long-term technology programs, and we highlighted the need for action in last year's NASA Authorization Act.

To quote Finding #10 from that Act:

> "NASA should make a sustained commitment to a robust long-term technology development activity. Such investments represent critically important 'seed corn' on which NASA's ability to carry out challenging and productive missions in the future will depend."

I would also note that the summary report of the Augustine panel that has been reviewing NASA's human space flight plans also acknowledged the importance of technology development:

- "The Committee strongly believes it is time for NASA to reassume its crucial role of developing new technologies for space."

That is a sentiment of the Augustine panel with which I heartily concur.

NASA's technology development activities are critical not just to NASA's future, but to the quality of life of our citizens and our nation's competitiveness.

Discussions of technology development can wind up sounding pretty "wonky", so let me be clear why I think NASA's efforts are so important and need to be supported.

Here's a picture of a standard commercial aircraft that I think makes my point.

As you look at it, you will see that almost all of its major systems and technologies came from research undertaken or funded by NASA.

Here is an aircraft that probably many Members of Congress get in several times a week, and yet I bet very few of them—or members of the public at large—recognize that NASA R&D made that plane possible.

And this picture is just one illustration of the impact of NASA's research on our society and our economy.

I have no doubt that each of NASA's other enterprises could provide similar examples *and I hope they will*—it's a story that needs telling and re-telling.

So 1 don't think any of the Members here today need to be convinced that NASA should pursue a vigorous program of technology development.

Rather, we want to explore what it will take to get such a revitalized program in place at the agency.

In that regard, I want to state my strong belief that we don't revitalize technology development at NASA by "robbing Peter to pay Paul".

That is, carving out funding from an already underfunded Constellation program so that the long-term technology program can be augmented would be penny-wise and pound-foolish—you don't fix one underfunded program by taking funding from another underfunded program and expect anything good to result.

In addition, I suspect that there may not be a "one-size-fits-all" organizational structure for technology development at NASA, but I want to hear from our witnesses on that topic, as I know that each of them have been thinking a lot about that issue.

But it's not just a question of either money or how the organizational deck chairs arearranged—NASA has to be smart and opportunistic in seeking out ways to get its technologies out to the private sector and to other potential government users.

That's probably a topic for a hearing in its own right, but perhaps our witnesses here today will have some thoughts on what NASA might do.

Well, I look forward to an interesting and informative discussion today.

However, in that discussion, I would ask my colleagues to refrain from asking our NASA witness about NASA's response to the report of the Augustine panel, which is scheduled to bereleased today.

He is not going to be able to comment on the report at this point, and we will have other opportunities to get NASA's perspectives on it in the coming weeks.

With that, I again want to welcome our witnesses, and I'd now like to turn to Mr. Olson for any opening remarks he might care to make.

Chairwoman GIFFORDS. And now I would like to turn to Mr. Olson for any opening comments that he would like to make.

Mr. OLSON. Madam Chairwoman, thank you for calling this morning's hearing to examine NASA's efforts to foster development of advanced and innovative technologies. Let me begin by thanking our witnesses for their appearance today before this subcommittee. I recognize that each of you spent considerable time and effort preparing for this hearing, and in some cases traveling considerable distances to be here. Please note that this committee appreciates—the subcommittee appreciates your efforts as well as the wisdom and experience that you bring and that we will refer to your guidance in the months and years ahead.

In the public's mind NASA is synonymous with highly-innovative, cutting-edge technologies. NASA and its predecessor agency, NACA [National Advisory Committee for Aeronautics], have amassed a century's worth of remarkable achievements that advance the state of the art in aeronautics and astronautics in many extraordinary ways. Collectively, they have directly contributed to this country's high standard of living both in terms of directly contributing to a strong industrial base but also through the unanticipated use of technologies and new and creative applications developed by the private sector.

It would be difficult to catalog the number and scope of innovations and the technological spin-offs that have sprung from their work. But suffice to say that the products springing from NASA's technological genius permeates our daily lives, most notably the transportation, communications, propulsion, and medical industries.

In recent years NASA has restructured the way it stimulates development of new technologies, moving away from an independent, centralized office towards a diverse, less-structured effort influenced more by the needs of individual missions and programs. Views expressed by the external science community seem to suggest that NASA ought to return to the former model.

I look forward to hearing from this morning's witnesses on the most appropriate way to perpetuate NASA's record of technology innovation and development. Issues I hope will be explored include how to best—how best to broadly reach across the science and engineering communities, to stimulate, develop, and assess the most creative needs, to what level of maturity should promising concepts be funded, and how can the most promising technologies be transferred into specific agency projects and missions, as well as benefit the commercial sector.

And one last issue. What is the best way to ensure that advanced concepts and technology development efforts have the necessary funding and management stability. I can't think of any other civilian federal agency that has done more to improve our Nation's economic and technical prowess than NASA. And it is not because NASA is in the business of advancing our social wellbeing. Rather their technological discoveries and innovations developed in the pursuit of challenging space and aeronautics missions have been acquired and adapted by others in many creative products and services. It is the genius of American people that has made taking those products and turn them into something for our economy.

And before closing, I want to again recognize and thank Chris Scolese for his long service and strong leadership at NASA. Through the first half of this year you have led the agency during an always-challenging period of transition between Administrations. Your steady hand and candor is appreciated by the Congress and more importantly by the men and women who work at NASA.

Thank you, Madam Chairwoman. I yield back my time.

[The prepared statement of Mr. Olson follows:]

PREPARED STATEMENT OF REPRESENTATIVE PETE OLSON

Madam Chairwoman, thank you for calling this morning's hearing to examine NASA's efforts to foster and manage the development of advanced and innovative technologies.

Let me begin by thanking our witnesses for their appearance today before this subcommittee. I recognize that each of you have spent considerable time and effort preparing for this hearing, and in some cases traveling considerable distance to be here. Please know that this subcommittee appreciates your efforts, as well as the wisdom and experience that you bring, and that we will refer to your guidance in the months and years ahead.

In the public's mind, NASA is synonymous with highly innovative, cutting edge technologies. NASA and its predecessor agency, NACA, have amassed a century's worth of remarkable achievements that advanced the state of the art in aeronautics and astronautics in many extraordinary ways. Collectively, they have directly contributed to this country's high standard of living, both in terms of directly contributing to a strong industrial base, but also through the unanticipated use of technologies in new and creative applications developed by the private sector. It would be difficult to catalog the number and scope of innovations, and the technological spin-offs that have sprung from their work. But suffice it to say that the products springing from NASA's technical genius permeates our daily lives, most notably in the transportation, communications, propulsion, and medical industries.

In recent years NASA has restructured the way it stimulates the development of new technologies, moving away from an independent, centralized office toward a diverse, less-structured effort influenced more by the needs of individual missions and programs.

Views expressed by the external science community seem to suggest that NASA ought to return to the former model.

I look forward to hearing from this morning's witnesses on the most appropriate way to perpetuate NASA's enviable record of technology innovation and development. Issues I hope will be explored include how best to broadly reach across the science and engineering communities to stimulate, develop and assess the most creative ideas; to what level of maturity should promising concepts be funded; and how can the most promising technologies be transferred into specific agency projects and missions, as well as benefit the commercial sector. And one last issue: What is the best way to ensure that advanced concepts and technology development efforts have the necessary funding and management stability?

I can't think of any other civilian federal agency that has done more to improve our nation's economic and technical prowess than NASA. And it's not because NASA is in the business of advancing our social well-being; rather, their technological discoveries and innovations—developed in the pursuit of challenging space and aeronautics missions—have been acquired and adapted by others in many creative products and services.

Before closing, I want to again recognize and thank Chris Scolese for his long service and strong leadership at NASA. Through the first half of this year he led the agency during an always challenging period of transition between Administrations. His steady hand and candor was appreciated by Congress, and more importantly, by the men and women at NASA.

Thank you, Madam Chairwoman. I yield back my time.

Chairwoman GIFFORDS. Thank you, Mr. Olson. Very well said. I am glad you are the Ranking Member. Is there anyone else that would like to make an opening statement?

Mr. Wilson.

Mr. WILSON. Thank you, Chairman, Chairwoman Giffords. Thank you for this important hearing, and thank you for the leadership that you have shown on Science and Technology.

NASA's efforts in the field of advanced concepts and technology development have not only moved the field of space and aeronautics forward but have improved our lives through the use of satellite communications, space-based weather observations, and aviation navigation systems.

In this time of transition and budget constraints I believe it is important that NASA continue to have a focus on the technologies necessary for not just the next space mission but the missions that are in our distant future.

Panelists, thank you for joining us today and providing your opinions and expertise to this subcommittee. I look forward to working with each of you, as well as my fellow committee members, as we seek to continue NASA's ability to explore the far reaches of this universe and inspire our country.

Thank you, Madam Chairwoman.

[The prepared statement of Mr. Wilson follows:]

PREPARED STATEMENT OF REPRESENTATIVE CHARLES A. WILSON

Thank you Chairwoman Giffords for holding this importanthearing.

NASA's efforts in the field of advanced concepts and technology development have not only moved the field of space and aeronautics forward, but have improved our lives thoughthe use of satellite communication, spaced-based weather observations, and aviation navigation systems. In this time of transition and budget constraints, I believe it isimportant that NASA continue to have a focus on the technologies necessary for not just the next space mission, but the missions that are in the distant future.

Panelists, thank you for joining us today and providing your opinions and expertise tothis Subcommittee. I look forward to working with each of you, as well as my fellow Committee members, as we seek to continue NASA's ability to explore the far reaches of this universe and inspire our country.

Chairwoman GIFFORDS. Anyone else?

Okay. At this time I would like to introduce our witnesses. First up we have Dr. Robert Braun, who is the Co-Chair of the National Research Council's Aeronautics and Space Engineering Board Committee to Review the NASA Institute for Advanced Concepts. We also have with us today Dr. Raymond S. Colladay, who is Vice Chair of the Committee on the Rationale and Goals of the U.S. Civil Space Program and Chair of the National Research Council's Aeronautics and Space Engineering Board. And we have with us Mr. Christopher Scolese, who is the Associate Administrator at NASA and who has served with distinction as the Acting NASA Administrator until Administrator Bolden was confirmed. So welcome all.

As our witnesses know, you will each have 5 minutes for your spoken testimony. Your written testimony has been included for the record for this hearing, and when you have completed each of your testimony, we will begin a round of questions, and all the members will have 5 minutes to question the panel.

We would like to start today with Dr. Braun.

STATEMENT OF DR. ROBERT D. BRAUN, CO-CHAIR OF THE COMMITTEE TO REVIEW THE NASA INSTITUTE FOR ADVANCED CONCEPTS, AERONAUTICS AND SPACE ENGINEERING BOARD, NATIONAL RESEARCH COUNCIL

Dr. BRAUN. Chairwoman Giffords, Ranking Member Olson, and members of the subcommittee, thank you for the honor of appearing before you today to discuss the approaches to strengthen NASA's advanced concept and technology development programs. My name is Robert Braun. The views I express today have been shaped through a 22-year career in aerospace engineering in both government and academic positions. Today I speak to you as the Co-Chair of the National Research Council's committee to review the NASA Institute for Advanced Concepts.

With your permission I would like to summarize my views this morning, leaving sufficient time to answer your questions. I would like to begin with a summary of our NRC report.

NASA established the NASA Institute of Advanced Concepts [NIAC] in 1998, to provide an independent, open forum for the external analysis and definition of revolutionary space and aeronautics concepts. These were concepts that could impact a NASA mission 10 to 40 years in the future.

Funded at approximately $4 million per year or roughly .02 percent of NASA's budget, NIAC operated for approximately 9 years and received a total of 1,309 proposals from which they made 126 phase one awards and 42 phase two awards, primarily to small businesses and universities throughout the country.

At its inception NIAC was envisioned as a cross-cutting program reporting to the agency's chief technologist. However, in 2004, NIAC program management within NASA was transferred into one of the mission directorates, NASA's Exploration Systems Mission Directorate, and in 2007, NIAC was terminated.

I would like to highlight the following four key findings and recommendations from our committee report. One, NIAC met its mission and accomplished its stated goals. Two, NASA and the Nation need a NIAC-like organization. Three, the original NASA implementation of NIAC as an external organization managed above and across the mission directorates was effective, and four, modifications could be made both within NIAC itself and within NASA to improve the effectiveness of this enterprise. Chief among these modifications would be potentially reestablishing an aeronautics and space systems technology development enterprise within NASA itself.

In my view a NASA strongly positioned for the future should include a brand of mission focused near-term, capability based, mid-range, and discipline based, long-term technology investments strategically guided by continuously engaged advanced concepts program.

However, at present there is no NASA organization responsible for the solicitation, evaluation, and maturation of advanced concepts or for the subsequent infusion of those worthy concepts into NASA's strategic planning process.

In addition, while mid-range capability-based technology investments are perhaps the most critical for a forward-looking agency like NASA, within NASA today it is this type of technology investment that is actually minimal. In my opinion this is not appropriate for an agency whose purpose includes demonstrating this Nation's scientific and technological prowess. Or one that is trying to inspire the next generation of engineers and scientists. A technology-poor NASA greatly hampers our aeronautics and spaceflight development programs.

As an example, we cannot continue to rely on 1970s era technology to land systems on Mars, particularly if we want to one day build towards eventual human exploration. Another example, as stated by both the Aldridge Commission in 2004, and the Augustine Commission this year, we cannot plan a sustainable human exploration program without strong technology leverage.

Based on these observations I suggest NASA establish a formal enterprise to continuously evaluate, prioritize, and mature a strategically selected set of technologies in the relevant environments. Many positive outcomes are likely from a long-term, broadly-focused NASA advanced concepts and technology development program.

Chief among these consequences is the provision of a more exciting aeronautics and space future than our country has today. A suite of game-changing space and aeronautic discoveries are within our Nation's grasps. Each of these advances would also serve as a spark to a technology-based economy, an international symbol of our country's scientific innovation, engineering creativity, and technological skill, and a component of the remedy to our Nation's scientific and mathematic literacy challenges.

Our Nation needs to dream big, and achieving large goals is precisely what America has come to expect of NASA. With a stronger focus on technology development NASA would be well poised to deliver on some of societies' grand challenges.

This completes my introductory remarks. I would be happy to respond to any questions you may have. Thank you.

[The prepared statement of Dr. Braun follows:]

PREPARED STATEMENT OF ROBERT D. BRAUN

Madame Chairwoman, Ranking Member Olson and members of the Subcommittee, thank you for the honor of appearing before you today to discuss approaches to strengthen NASA's advanced concept and technology development programs. My name is Robert D. Braun. The views I express today have been shaped through a twenty-two year aerospace engineering career in government and academia. For sixteen years, I served on the technical staff of the NASA Langley Research Center. At NASA, I developed advanced space exploration concepts, managed multiple technology development efforts, and contributed to the design, development, test and operation of several robotic Mars flight systems. For the past 6 years, I have served on the faculty of the Daniel Guggenheim School of Aerospace Engineering at the Georgia Institute of Technology. As Director of Georgia Tech's Space Systems Design Laboratory, 1 lead an active research and educational program focused on the design of advanced flight systems and technologies for planetary exploration. The advanced space systems concept and technology maturation skills being developed by the undergraduate and graduate students at Georgia Tech are of significant interest to NASA, the U.S. Air Force, DARPA, our national labs, industry, and others in academia. It gives me great pride to work closely with these students, who are on their way to becoming the space systems engineers of our nation's future.

Today, I speak to you as the Co-chair of the National Research Council's Committee to Review the NASA Institute for Advanced Concepts, which recently released our report *Fostering Visions for the Future: A Review of the NASA Institute for Advanced Concepts.* The committee's twelve members were chosen by the NRC for their experience with advanced space and aeronautical concepts and their insight into cogent approaches to spark scientific innovation and creativity. They represent a diverse cross-section of aerospace sector experience, including NASA, DARPA, the SETT Institute, industry, and academia. The committee was co-chaired by Dianne S. Wiley, a Technical Fellow at Boeing Phantom Works and myself. I must say that it was a pleasure to work through the NRC with this talented and experienced group of people.

In response to the first question posed by the subcommittee, I would like to begin by summarizing our committee report.

Fostering Visions of the Future: A Review of the NASA Institute for Advanced Concepts

NASA established the NASA Institute for Advanced Concepts (NIAC) in 1998 to provide an independent, open forum for the external analysis and definition of revolutionary space and aeronautics concepts to complement the advanced concepts activities conducted within the Agency. Funded at approximately $4 million per year (roughly 0.02% of NASA's budget), MIAC received a total of $36.2 million in NASA funding during the 9 years of its existence. As directed by the NASA SOW, NIAC focused on revolutionary advanced concept studies that could impact a NASA mission 10 to 40 years in the future. NIAC inspired an atmosphere of innovation that stretched the imagination and encouraged creativity. In response to its yearly solicitations, NIAC received a total of 1309 proposals, and made 126 Phase I awards and 42 Phase II awards, primarily to small businesses and universities, but also to large businesses and national laboratories. To reduce costs and maximize public accessibility, NIAC utilized an open, web-based environment to conduct solicitations, perform peer review, administer grant awards, and publicize its activities. NIAC received an "Excellent' performance rating in each NASA annual review held. Many NIAC grantees went on to receive additional funding for continued development of their concept from NASA, other government agencies or private industry. In addition to developing revolutionary concepts, NIAC placed an emphasis on science and engineering education as well as public outreach. At its inception, NIAC was envisioned as a crosscutting program reporting to the Agency's Chief Technologist. In 2004, when the NASA Office of Aerospace Technology was dissolved, NIAC program management was transferred into the NASA Exploration Systems Mission Directorate. In 2007, NIAC was terminated.

In 2008, Congress directed the National Research Council (NRC) to conduct a review of the effectiveness of NIAC and to make recommendations concerning the importance of such a program to NASA and to the nation. Our committee was given the following statement of task:

1) Evaluate NIAC's effectiveness in meeting its mission.
2) Evaluate the method by which grantees were selected.
3) Make recommendations on whether NIAC or a successor entity should be funded by the Federal Government.
4) Make recommendations as to how the Federal Government in general and NASA in particular should solicit and infuse advanced concepts Into its future systems.

In evaluating NIAC's performance, the committee addressed the following questions:

1) To what extent were the NIAC-sponsored advanced concept studies innovative and technically competent?
2) How effective was NIAC in infusing advanced concepts into NASA's strategic vision, future mission plans, and technology development programs?
3) How relevant were these studies to the aerospace sector at large?
4) How well did NIAC leverage potential partnerships or cost-sharing arrangements?
5) What potential approaches could NASA pursue in the future to generate advanced concepts either internally or from external sources of innovation?

The key findings and recommendations from our report can be summarized in the following seven statements:

1) NIAC met its mission and accomplished its stated goals. The committee found that NIAC's approach to implementing its functions successfully met NASA-defined objectives, resulted in a cost-effective and timely execution of advanced concept studies, afforded an opportunity for external input of new ideas to the agency, and subsequently provided broad public exposure of NASA programs. NIAC was successful in encouraging and supporting a wide community of innovators from diverse disciplines and institutions as evidenced by receipt of 1309 proposals in its 9-year lifetime. The 126 NIAC Phase I studies were led by a total of 109 distinct principal investigators, each of whom led a research team of 3-10 personnel, often across multiple organizations. The majority of the NIAC-supported efforts were highly innovative. Many were successful. in pushing the state of the art. Overall, the efforts supported produced results commensurate with the funding and risk involved.

2) NIAC had infusion successes and challenges. One important NIAC performance metric defined in the NASA SOW was achievement of 5 to 10 percent infusion of NIAC-developed Phase II concepts into NASA's long-term plans. One way to gauge such infusion is to look at the receipt of post-NIAC funding for the continued development of a NIAC-funded concept. The committee found that 14 NIAC Phase I and Phase II projects, which were awarded $7 million by NIAC, received an additional $23.8 million in funding from a wide range of organizations, demonstrating the significance of the nation's investment in these NIAC advanced concepts. NIAC matured 12 of the 42 Phase II advanced concepts (29 percent), as measured by receipt of post-NIAC funding. In fact, 9 of these (21 percent) received post-NIAC funding from NASA itself. Over the long term, the ultimate criterion for NIAC success is the number of funded projects that make their way into the relevant NASA mission directorate decadal survey, strategic plan, or mission stream. The committee found that three NIAC Phase II efforts (7 percent of the Phase II awards) appear to have impacted NASA's long-term plans. Of significance, two of these efforts have either already been incorporated or are currently under consideration by the NRC Astronomy and Astrophysics Decadal Survey as future NASA missions: the MAXIM x-ray interferometry concept for black hole imaging and the New Worlds Observer constellation for exoplanet discovery. Considering the 40-year planning horizon of NIAC activities coupled with the 9-year existence of MIAC, the committee believes it is likely that the number of NIAC Phase II projects considered for NASA missions will continue to increase over time.

On the other hand, by design, the maturity of NIAC Phase II products was such that a substantial additional infusion of resources was needed before these advanced concepts could be deemed technically viable for implementation as part of a future NASA mission or flight program. The committee found that this technology readiness immaturity created infusion difficulties for the NIAC program and innovators, causing promising ideas to wither on the vine.

3) NASA and the nation need a NIAC-like organization. NASA is now an agency largely oriented toward flight-system development and operations. Priorities have thus diminished within NASA for long-range research and development efforts. At present, there is no NASA organization responsible for solicitation, evaluation, and maturation of advanced concepts (defined as those at technology readiness level one or two) or responsible for subsequent infusion of worthy concepts into NASA planning and development activities. Over the past few years, such NASA efforts have been ad hoc, lacking in long-term stability, and not integrated into the agency's strategic planning process. Managed in this fashion, advanced concept efforts will rarely produce mature products and the agency is at risk of driving away many of its most creative personnel. Our committee believes that NASA and the nation would be well served by maintaining a mechanism to investigate visionary, far-reaching advanced concepts as part of NASA's mission.[1] Concepts deemed feasible could be used to inform NASA's strategic planning process. Long-term, these concepts and technologies offer the potential for dramatic improvements in performance and/or cost of future aeronautical and space systems. As such, the committee recommends that NASA should reestablish a NIAC-like entity, referred to in our report as NIAC2, to seek out visionary, far-reaching, advanced concepts with the potential of significant benefit to accomplishing NASA's charter and to begin the process of maturing these advanced concepts for infusion into NASA's missions. The existence of such an organization would also demonstrate that NASA continues to be a driver of innovation and technological competitiveness, potentially serving as a critical element of NASA's public and educational value to the nation.

4) The original NASA implementation of NIAC as an external organization managed above and across the mission directorates was effective. When it was initially formed, NIAC was managed by a high-level agency executive concerned with the objectives and needs of all NASA enterprises and missions. The committee found that NIAC was most successful as a program with crosscutting applicability to NASA's enterprises and missions. When it was transferred to a mission-specific directorate, NIAC lost its alignment with sponsor objectives and priorities. To allow for sustained implementation of NIAC2 infusion objectives, the committee recommends that NIAC2 report to the Office of the Administrator, be outside mission directorates, and be chartered to address NASA-wide mission and technology needs. To increase NIAC2's relevance, NASA mission directorates should contribute thematic areas for consideration in the proposal solicitation process. The committee also recommends that this NIAC2 organization be funded and administered separately from NASA development programs, mission directorates, and institutional constraints. Future NIAC2 proposal opportunities should continue to be managed and peer-reviewed outside the agency.

5) NIAC2 modifications should be made to improve effectiveness. While NIAC's Internet-based technical review and management processes were found to be effective and should be continued in NIAC2, the committee found a few policies that may have hastened NIAC's demise. Key among these was (1) the exclusive focus on revolutionary advanced concepts, (2) the exclusion of NASA personnel from participation in NIAC awards or research teams, and (3) the immaturity of NIAC Phase II products relative to that required for implementation as part of a future NASA mission or flight program.

By definition, visionary advanced concepts will not be near-term. However, in our committee discussions, it was felt that NIAC's complete focus on revolutionary concepts (as directed in its NASA SOW) was too long-term, creating a cultural mismatch between the NIAC products and its mission-focused sponsors and causing infusion difficulties for the NIAC innovators. As such, the committee recommends that the key selection requirement for NIAC2 proposal opportunities be that the concept is scientifically and/or technically innovative and has the potential to provide major benefit to a future NASA mission of 10 years and beyond. While 10 years and beyond includes concepts that could be 40 years or farther in the future, the com-

[1] Section 102.c.4 of the National Aeronautics and Space Act of 1958 includes provision for the conduct of the aeronautical and space activities of the United States toward establishment of long-range studies of the potential benefits to be gained from, the opportunities for, and the problems involved in the utilization of aeronautical and space activities for peaceful and scientific purposes.

mittee felt that these modifications in focus would likely result in NIAC2 efforts with a higher probability of infusion into NASA's strategic planning process.

NIAC was formed to provide an independent, open forum for the external analysis and definition of space and aeronautics advanced concepts to complement the advanced concepts activities conducted within NASA; hence, NIAC solicitations were closed to NASA participants. However, NIAC was formed at a time when there was adequate funding internal to NASA for development of novel, long-term ideas. As internal NASA funding for advanced concepts and technology diminished or became more focused on flight-system development and operations, the cultural disconnect between the development activities internal and external to the agency grew, and transitioning of NIAC concepts to the NASA mission directorates became more difficult. The committee recommends that future NIAC2 proposal opportunities be open to principal investigators or teams both internal and external to NASA.

In addition, the committee believes that the potential for receipt of a NIAC2 Phase III award is needed to aid the transition of the most highly promising projects. Therefore, the committee recommends that future NIAC2 proposal opportunities include the potential selection of a small number of Phase III "proof of concept" awards for up to $5 million each over as much as 4 years to demonstrate and resolve fundamental feasibility issues and that such awards be selected jointly by NIAC2 and NASA management.

6) NASA modifications should be made to improve effectiveness. The lack of a NASA interface to receive the hand-off of promising projects was a persistent NIAC challenge. To improve the manner in which advanced concepts are infused into its future systems and to build a culture that continuously strives to advance technology, the committee recommends that NASA consider reestablishing an aeronautics and space systems technology development enterprise.[2] Such an organization would serve to preserve the leadership role of the United States in aeronautical and space systems technology.[3] Its NIAC2-oriented purpose would be to provide maturation opportunities and agency expertise for visionary, far-reaching concepts and technologies. NASA's considerations for such an enterprise should include implications for the agency's strategic plan, effective organizational approaches, resource distributions, field center foci, and mission selection process. Increased participation of NASA field center personnel, beyond review and management functions, should also significantly enhance advanced concept maturation and infusion into NASA mission planning. The committee also recommends identification of center technical champions and provision for the technical participation of NASA field center personnel in NIAC2 efforts. Participation of NASA personnel is expected to increase as NIAC2 projects mature.

7) The budget requirement for a strong advanced concepts development activity reaches a steady-state value of approximately $10M per year. Our committee believes that the NIAC was generally funded appropriately (approximately $4M/year) for its stated Phase I and Phase II objectives. We believe that NIAC2 proposal opportunities should be defined as follows: Phase I up to $100,000 each for 1 year; Phase II, up to $500,000 each for 2 years; Phase III proof-of-concept awards for up to $5 million each over as much as 4 years. Clearly, the number of such awards could be used as a control on the overall program budget. For example, in the first year of NIAC2, perhaps a dozen Phase I awards would be made for $1.2M, plus administrative costs. Including 4 Phase II awards in the following year would push the required yearly budget to approximately $2.2M (plus administrative costs). As a strawman, note that if NIAC2 funded 12 Phase I awards, 4 Phase II awards, and 1 Phase Ill award in each subsequent year, the budget requirement would increase by $1.25M each year until reaching a steady-state value of $8.2M in year six and beyond (plus administrative costs). In a strategy like this, the overall program budget is largely dependent on selection of the Phase III awards. If NASA saw value in the potential offered by multiple Phase III proposals, additional funds could be secured. If funding were tight in a given year, no Phase III awards would be made.

NIAC2 funding decisions should be made within the context of a well-funded NASA aeronautics and space systems technology enterprise that is both actively

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[2] Similar findings are made in *A Constrained Space Exploration Technology Program: A Review of NASA's Exploration Technology Development Program,* The National Academies Press, Washington, D.C., 2008; and *America's Future in Space: Aligning the Civil Space Program with National Needs,* The National Academies Press, Washington, D.C., 2009.

[3] Section 102.c.5 of the National Aeronautics and Space Act of 1958 includes provision for the conduct of the aeronautical and space activities of the United States for the preservation of the role of the United States as a leader in aeronautical and space science and technology and in the application thereof to the conduct of peaceful activities within and outside the atmosphere.

seeking advanced system concepts and maturing the requisite technological solutions. Large-scale technology development aspects of this enterprise were beyond the committee's charter, and would require considerably more funding than the $10M proposed for NIAC2. These larger funding issues are addressed in my response to the subcommittee's next question.

In addressing the subcommittee's remaining questions, I am guided by my personal experience in NASA and academia. Although the NRC NIAC committee's discussions touched on these topics, this committee was not specifically tasked to address these broader subjects.

In response to the second question posed by the subcommittee, I would like to define the scope of a broadly focused long-term program dedicated to stimulate innovation and develop new concepts and capabilities, and then describe the results our nation should expect from such a program.

Three Technology Development Classes and the Need for a Strengthened Capability-Based Technology Development Effort within NASA

In my experience, there are three general classes of technology development programs: mission-focused (near-term), discipline-based (long-term), and capability-based (mid-range). A NASA strongly positioned for the future should sponsor a blend of these three technology development classes, strategically guided by the results of a continuously engaged advanced concepts program. It is in this way that an advanced concepts program can be used to inform an organization's strategic planning process and provide value to its technology investment decisions. The success of such an enterprise will clearly be dependent on the group of program managers and systems engineers making technology readiness assessment and technology investment decisions for the agency. Passionate, hard-charging systems engineers and program managers who remain objectively focused on the long-term development needs of the agency, independent of the agency's institutional constraints, and out of the proverbial technology sandbox will be required. A series of competitively awarded activities spanning near-term, mid-term and long-term aeronautics and space systems needs is likely the best means of implementing a successful technology development program. Competitive awards should be made based on an objective assessment of the agency's strategic need, the proposed technical scope and product realism.

Mission-focused technology programs abound in most current large NASA programs. Consider, for example, NASA's human spaceflight program. In development of the Constellation architecture, priority was given to near-term systems with the goal of an early initial operational capability—existing technology with low risk was the Constellation mantra. In fact, funding from a wide range of NASA advanced technology programs was redirected to enable this capability. However, even with its near-term focus and budgetary challenges, the Constellation program required and funded a small number of mission-focused technologies to enable qualification of the key technologies required for mission success. These mission-focused technology programs include a lunar-return capable heatshield, an autonomous landing and hazard avoidance system for lunar landing operations, and lunar in-situ resource utilization.[4] Without such technological advances, NASA's current approach to returning humans to the Moon would be dramatically impacted. Similar mission-focused technology investments have allowed NASA's robotic exploration program to pursue advanced science missions like the Mars Science Laboratory and Webb Space Telescope. Clearly, these are important investments that require NASA funding. However, these mission-focused activities are not the only technology investments that an agency that prides itself on innovation and pushing-the-boundary should pursue.

Within NASA, the ARMD Fundamental Aeronautics program is the only present program of which I am aware that is pursuing discipline-based technological solutions. Longer term by nature and generally funded at a much lower level, these technology advances are often pursued with the promise of enabling dramatic performance improvements in one or more aerospace disciplines, and the potential for major system advances across multiple future programs. While ARMD funding is largely directed internal to NASA and its aeronautics challenges, examples of possible discipline-based technology investments include laminar flow control technology, high-temperature materials and structures, hypersonic airbreathing propulsion, advanced in-space propulsion, robust navigation and control algorithms, high-efficiency solar power systems, radiation protection systems, and inflatable struc-

[4] *A Constrained Space Exploration Technology Program: A Review of NASA's Exploration Technology Development Program,* The National Academies Press, Washington, D.C., 2008.

tures. In addition, NASA can now offer unique, discipline-based microgravity research opportunities through effective utilization of the International Space Station.

The United States boasts a tremendously successful robotic Mars program. Continuous orbital observations of the Mars surface have been made for more than a decade and six robotic systems have now been placed on the surface of Mars. While each of these six landed missions has been an incredible technological accomplishment in itself, these robotic systems have each landed less than 0.6 metric tons within landing footprints on the order of hundreds of kilometers. At present, robotic exploration systems engineers are struggling with the challenges of increasing landed mass capability to just 1 metric ton (less than half the Earth weight of a 2009 Ford Explorer) while improving landed accuracy to 10 kilometers for the Mars Science Laboratory project. Meanwhile, the planning of subsequent robotic exploration missions under consideration for the 2020 decade may require several metric tons in landed mass capability and current plans for human exploration of Mars call for landing 40–80 metric ton surface elements within close proximity (tens of meters) of pre-positioned robotic assets. These future mission requirements cannot be met with NASA's present suite of entry, descent and landing technologies and are one reason that human Mars exploration is viewed as a "bridge too far" by many in the aerospace and public policy communities. However, analysis suggests that there are a handful of promising entry, descent and landing capabilities that may prove feasible for these larger landed systems, enabling future Mars exploration concepts of which today we can only dream. These technologies are termed capabilities because these same general systems may also prove advantageous for Earth-return missions or missions to other planets—such developments are not specific to a single mission. Additional capability-focused technology needs abound in deep space exploration, astrophysics, aeronautics, and Earth science. In each case, NASA technology investment is critical—for without such an investment, these future missions will simply not occur.

Strategic assessment of our nation's future spaceflight technology needs was performed by both the Aldridge Commission [5] in 2004 and the Augustine Commission [6] in 2009. Each commission concluded that successful development of a set of enabling technologies (or capabilities) is critical to attainment of human and robotic exploration objectives within reasonable schedule and affordable cost. The NASA Authorization Act of 2008 furthered this sentiment by codifying it into law. Section 405 of this Act states, *"A robust program of long-term exploration-related research and development will be essential for the success and sustainability of any enduring initiative of human and robotic exploration of the solar system."* This Act further states that this program shall not be tied to specific flight projects. I strongly agree with the capability-based technology sentiment expressed by these two Presidential Commissions and the NASA Authorization Act of 2008.

While mid-term, capability-based technology investments are perhaps the most critical for a forward-looking Agency like NASA; within NASA today, this type of technology investment is minimal. NASA presently invests approximately $1.35B on a range of near-term, mid-range and long-term technologies [7] Approximately two-thirds of this investment is directed toward near-term mission-focused technologies that are strongly coupled to NASA's existing programs. This allocation leaves approximately $0.45B (less than 3% of NASA's total budget) for capability-based technology development and discipline-based fundamental research that is not tied to existing program requirements. However, at present, a majority of these remaining funds are allocated to the longer-term ARMD Fundamental Aeronautics program, leaving little mid-range capability-based technology investment.

Anticipated Results from a Broadly Focused Long-Term NASA Program to Develop Advanced Concepts and their Associated Technologies

Many positive outcomes are likely from a long-term, broadly focused NASA advanced concepts and technology development program that include mission-focused, capability-based and discipline-based components. Chief among these consequences is the provision of a more vital and productive aeronautics and space future than our country has today. Each year, in the first lecture of my freshman *Introduction to Aerospace Engineering class,* I share with these recent high-school graduates a list of accomplishments that I believe our nation's civil aeronautics and space program is capable of achieving in my lifetime:

[5] *Report on the President's Commission on Implementation of U.S. Space Exploration Policy: A Journey to Inspire, Innovate and Discover,* June 2004.

[6] *Summary Report on the Review of U.S. Human Spaceflight Plans,* September 2009.

[7] *NASA Innovation and Technology Initiative: Enabling NASA's Future and Addressing National Needs,* Briefing to NRC ASEB by Dr. Laurie Leshin, NASA, October 2009.

Ten Anticipated Paradigm-Changing Civil Aeronautics and Space Advances

1) Quantify Causes, Trends and Effects of Long-Term Earth Climate Change
2) Accurately Forecast the Emergence of Major Storms and Natural Disasters
3) Develop and Utilize Efficient Space-Based Energy Sources
4) Prepare an Asteroid Defense
5) Identify Life Elsewhere in our Solar System
6) Ientify Earth-like Worlds Around Other Stars
7) Initiate Interstellar Robotic Exploration
8) Achieve Reliable Commercial Low-Earth Orbit Transportation
9) Achieve Affordable Supersonic Business Travel
10) Achieve Permanent Human Presence Beyond the Cradle of Earth

Advances of this type are more than a single professor's dream—they are a spark to a technology-based economy, an international symbol of our country's scientific and technological leadership, and a component of the remedy to our nation's scientific and mathematics literacy challenges. I genuinely believe that game-changers like these are within our nation's grasp. Capability-based technology investment, focused leadership and stability of purpose are the only elements holding us back. Landing humans on Mars requires an investment in advanced technology, as does developing a telescope capable of detecting Earth-size planets around other stars, flying a new generation of human-rated launch systems, or identifying life elsewhere in our solar system. Our nation needs to dream big, and large goals, like these, are precisely the kind of objectives that our nation has come to expect of NASA. It is equally clear that in the absence of sustained, broad-based technology investments, the United States will not continue to make significant advances in aeronautics, space, and the associated sectors of our society. Investments of this scale will not be without cost. I believe that our nation would be well served by investing at least 10% of NASA's budget in support of the technologies required to dramatically advance entirely new aeronautics and space endeavors (in contrast to an investment of less than 3% today).

In this same class, I often ask the students why they are choosing to become aerospace engineers. In general, these 18-year olds are motivated by a strong desire to contribute to humanity's future by solving our nation's grand technological challenges. They want to work with others (and in organizations) who feel the same way. As such, a well managed, broad-based advanced concepts and technology development enterprise can serve as a catalyst to revitalize our nation's aerospace workforce with the best and brightest of tomorrow. Such an organization can also serve to demonstrate that NASA continues to be a driver of scientific innovation, engineering creativity and technological competitiveness for our country and around the world.

NASA technology innovation efforts are also bound to stimulate the university and commercial sectors, create new business and increase the number of high-tech jobs across our nation. As a small-scale example, NIAC efforts contributed to the launch of a new business division within ENSCO and two entirely new businesses (Space Elevator: Black Line Ascension and Liftport).

In response to the third question posed by the subcommittee, I would like to briefly discuss the additional uncertainty and risk associated with developing new concepts and technologies within NASA's flight projects.

Technology Development within NASA's Missions Contribute Significant Cost and Schedule Risk

Implementation of NASA space flight missions is fraught with complex systems engineering challenges due to the extreme environment in which these systems must reliably operate. Completing a spaceflight mission within its established budget and schedule constraints is one of the most difficult undertakings in the engineering field. As such, I have great respect for those within NASA who have succeeded in these endeavors. These missions demand a focus on technical excellence across the organization, a systems engineering approach to project implementation, technical insight and crisp decision-making from project managers, clear communication across the organization, and early risk identification, prioritization, and mitigation. In addition, trades between performance, cost, schedule and risk are generally constrained by program-level decisions and public policy decisions made outside the project's control. In my view, adding requirements for technology development to a NASA flight project in the implementation. phase is inherently risky and a poor program management practice.

In March 2009, in testimony presented before this subcommittee entitled, *NASA Projects Need More Disciplined Oversight and Management to Address Key Challenges,* a GAO representative described her analysis of thirteen NASA flight projects in the implementation phase. In this project phase, systems design is completed, scientific instruments are integrated, and the flight system is fabricated and prepared for launch, Prior to entering the implementation phase, it is standard NASA practice to have finalized requirements, concepts and technologies and establish a baseline project plan. Ten of the thirteen NASA projects in the implementation phase assessed by the GAO experienced significant cost and/or schedule growth from their project baselines. Of the five causes of cost and/or schedule growth cited by the GAO, two issues pertain directly to technology development risk: technology immaturity and modifications required to previously considered heritage items. The common symptom of these two causes is a technological readiness considerably below that estimated by the project. The GAO report concludes, "Simply put, projects that start with mature technologies experience less cost growth than those that start with immature technologies." I fully agree with this statement.

NASA also knows this lesson. In fact, NASA requires all technologies used in its competitive missions to be at a technology readiness level of six (system/subsystem model or prototype demonstration in a relevant environment) or higher by the beginning of the project implementation phase. In a competitive proposal, failure to have such a technology maturation plan is cited as a major weakness. As such, few, if any, competed missions begin plementation while still developing technology. However, this same approach is not generally applied to NASA's larger space flight programs, which often rely on large technology advancements as part of project implementation due to the significant performance gains that they are attempting to achieve. As a result, large, non-competed projects tend to encounter significant cost overruns and/or schedule delays as a result of technology risk. Insisting on an adequate formulation phase in which technology risk is firmly retired, before committing project implementation funding, is the most straightforward means for reducing the cost and schedule risk of these large NASA missions.

In response to the fourth question posed by the subcommittee, I would like to briefly discuss the time horizons required for the development of advanced concept and technology development programs.

Time Horizons on Advanced Concept and Technology Development Programs

A long-term, broadly focused NASA advanced concepts and technology development enterprise should span multiple timeframes in which the maturation plan for a given technology should be coupled to the agency's strategic planning process through ongoing NIAC2 advanced concept studies. Within this enterprise, one can envision a blend of technology development timeframes spanning 2–5 years for mission-focused technology (moderate $ investment), 5–15 years for capability-based technology (large $ investment), and 15–40 years for discipline-based technology (modest $ investment). Competitive awards across these technology classes should be made on a 2–3 year cycle depending on the milestones achieved and funding availability. Technology project development lifecycles spanning 2–5 years are anticipated. In this scenario, the technology development enterprise should partner with NASA's existing flight programs such that the mission-focused technologies it funds benefit from at least a 50% cost contribution from the relevant mission directorate. This strategy should allow for capability-based technologies, which are not tied to NASA's existing missions, to dominate the investment portfolio of the technology development enterprise. This emphasis on capability-based technology is absent in NASA today. A broad range of discipline-based investments should also be funded at a lower level.

Use of NIAC2 as a long-term asset to inform NASA's strategic planning process is a key component of this plan. NIAC2 can look out for advanced concepts beyond the current development programs. It can work on the edges where requirements are not yet known, focused on what program managers would want if they knew that they needed it. However, it is also clear that for this independent organization that nurtures technology push to succeed, it must be partnered with a substantive NASA enterprise of technology pull, managed at the agency-level and working in concert with NASA's existing mission directorates.

Summary

There is little capability-based technology development within NASA today and no NASA organization responsible for solicitation, evaluation, and maturation of advanced concepts or responsible for subsequent infusion of worthy concepts into

NASA's strategic planning process. In my view, this is not acceptable for an agency whose purpose includes demonstrating this nation's scientific and technological prowess, or one that is trying to Inspire the next generation of engineers and scientists. A technology-poor NASA greatly hampers our aeronautics and space flight development programs. We cannot continue to rely on 1970's-era technology to land systems on Mars, particularly if we want to build toward eventual human exploration. We cannot continue to explore the solar system robotically without advanced in-space propulsion and atmospheric flight technologies as part of our future mission portfolio. We cannot plan a sustainable human exploration program without strong technology leverage. Strategic assessment of our nation's future spaceflight technology needs was performed by both the Aldridge Commission in 2004 and the Augustine Commission in 2009. Each commission concluded that successful development of a set of enabling technologies (or capabilities) was critical to attainment of space exploration objectives within a reasonable schedule and affordable cost. The NASA Authorization Act of 2008 furthered this sentiment by codifying it into law. Based on these inputs, I suggest NASA establish a formal enterprise to continuously evaluate, prioritize, and mature these technologies in the relevant environments. Within this enterprise, a blend of technology development activities spanning mission-focused technology (2–5 year maturation timeframe, moderate $ investment), capability-based technology (5–15 year maturation timeframe, large $ investment), and discipline-based technology (15–40 year maturation timeframe, modest $ investment) should be pursued.

Our nation would be well served by investing at least 10% of NASA's budget in support of the technologies required to dramatically advance entirely new aeronautics and space endeavors (in contrast to an investment of less than 3% today). This investment would include a small amount for advanced concepts so difficult to achieve that their chance of individual success within a decade is less than 10%, yet concepts so innovative that their success could serve as game-changers for this vital, national industry. Our nation needs to dream big, and large goals are precisely what our nation has come to expect of NASA. Major breakthroughs are needed to address our society's energy, health, transportation, and environment challenges. While NASA investments alone will not solve these grand challenges, NASA has proven to have a unique ability to attract and motivate many of the country's best young minds into educational programs and careers in engineering and science. Although it is not possible to predict which advanced aerospace concepts will produce.paradigm-shifting results, it is certainly true that, in the absence of research on such concepts, the United States will not make revolutionary technological advances in aeronautics and space and long-term societal goals in these and related areas will remain beyond our reach.

BIOGRAPHY FOR ROBERT D. BRAUN

Dr. Robert D. Braun is the David and Andrew Lewis Professor of Space Technology in the Daniel Guggenheim School of Aerospace Engineering at the Georgia Institute of Technology. He leads an active research and educational program focused on the design of advanced flight systems and technologies for planetary exploration and is responsible for undergraduate and graduate instruction in the areas of space systems design, astrodynamics and planetary entry. Prior to joining Georgia Tech, Dr. Braun worked at NASA for sixteen years where he developed advanced space exploration concepts, managed multiple technology development efforts, and contributed to the design, development, test and operation of several robotic Mars flight systems, including entry, descent and landing systems for the Mars Pathfinder, Mars Microprobe and Mars Sample Return missions. Dr. Braun has received the 1999 AIAA Lawrence Sperry Award, two NASA Exceptional Achievement Medals, seven NASA Group Achievement Awards, and two NASA Inventions and Contributions Board awards. Dr. Braun received a B.S. in Aerospace Engineering from Penn State in 1987, M.S. in Astronautics from the George Washington University in 1989, and Ph.D. in Aeronautics and Astronautics from Stanford University in 1996. He is an AIAA Fellow and the principle author or co-author of over 175 technical publications in the fields of planetary exploration, atmospheric entry, multidisciplinary design optimization, and space systems engineering.

Chairwoman GIFFORDS. Thank you, Dr. Braun.

Dr. Colladay.

STATEMENT OF DR. RAYMOND S. COLLADAY, VICE CHAIR OF THE COMMITTEE ON RATIONALE AND GOALS OF THE U.S. CIVIL SPACE PROGRAM, AERONAUTICS AND SPACE ENGINEERING BOARD, NATIONAL RESEARCH COUNCIL

Dr. COLLADAY. Thank you, Chairwoman Giffords and members of the subcommittee. I appreciate the opportunity to appear before you today to address a subject that is very important to the country and has been particularly in my crosshairs for the last 3 or 4 years in the National Research Council [NRC] and Aeronautics and Space Engineering Board.

Aerospace is one sector where the U.S. remains preeminent, and we have in large part NASA to thank for that, but our future leadership depends on continued investment in long-term, advanced technology R&D. In our NRC report on America's Future in Space we describe the many reasons why space is important to the country, including the recognition that space generates high-end jobs in science, engineering, and math, supplying the workforce for the aerospace sector of our economy that remains the envy of the world.

Beyond that it inspires an interest in technical fields of study that is and will continue to be of vital importance to our economic competitiveness. Sustaining U.S. leadership in space depends on having a sufficiently broad and deep technology base that pushes the frontiers of our knowledge, leads to innovation and new systems, and challenges conventional wisdom with transformational technology.

When it comes to truly game-changing technical breakthroughs, a long-term view is particularly important, and such a perspective is almost exclusively the domain of the government. Long-term advanced technology R&D does not happen in industry because the return on investment is years away, and it does not happen in academia without sustained, stable government funding.

With that perspective in mind I would like to make a few observations. To fulfill its broad mandate in civil and commercial space, NASA should revitalize its advanced technology development program as a priority mission area. Its technology R&D mission should be independent of the major development programs and report to the administrator or some equivalent management structure of our government's model to give it the stature equal to the agency's other mission areas. In our report we refer to a DARPA [Defense Advanced Research Projects Agency]-like organization in NASA to convey this spot. It should engage the best science and engineering talent in the country wherever it resides, in universities, industry, NASA centers, and other government laboratories.

It should be relieved of at least the first order of institution requirements to maintain core competencies at the ten NASA centers. In order to ensure that the research can draw on the best ideas and talent wherever it should reside. It should serve not just NASA but civil space customers including commercial space and other government agencies or departments much like its aeronautics program and its predecessor NACA has done for almost 100 years.

A comprehensive assessment of the current state of the art of advanced space technology would be helpful to ensure that any new investment in technology R&D would be building on the most advanced technology base currently available.

Whatever governance model NASA chooses for managing a technology enterprise, it needs to address technology relevance and transition. The ultimate user community determines the products of technology R&D remain useful and relevant, and technology transition is a process that must be managed with all the stakeholders involved.

In summary, the country expects NASA to be a leader, pushing the frontiers of air and space applications and missions as called for in the Space Act. But to do so NASA needs to replenish the underpinning technology that makes it possible.

That completes my brief summary of my remarks, and I would be open, of course, to questions later.

[The prepared statement of Dr. Colladay follows:]

PREPARED STATEMENT OF RAYMOND S. COLLADAY

Madam Chairwoman and members of the Subcommittee, I am pleased to appear before you today. My name is Ray Colladay and the personal views I express are shaped by my 40 years of experience in aerospace, through positions I have held in government, industry, and academia. I chair the Aeronautics and Space Engineering Board (ASEB) of the National Research Council (NRC) and also served as Vice Chair of the Academy funded study on "AMERICA'S FUTURE IN SPACE: ALIGNING THE CIVIL SPACE PROGRAM WITH NATIONAL NEEDS". Although I have insights into NASA acquired through those and other positions, my views are my own and do not represent an official position of the NRC.

With your permission, I would like to submit my prepared testimony for the record and summarize my views for you here this morning.

In the previously mentioned NRC report on "America's Future In Space", we observed that space has become ubiquitous and permeates nearly every aspect of our daily lives. We concluded that if properly aligned and coordinated, U.S. civil space can provide technological, economic, and societal benefits that contribute to solutions to the nation's most pressing problems. The study detailed seven recommendations for U.S. leadership in space, but among the most actionable of those recommendations—one that we called "foundational" in the sense that it was among those that enabled other goals and recommendations to be met—was that NASA needs to revitalize its advanced technology development program as a priority mission area in the agency.

Because of budget pressures and institutional priorities, however, NASA has largely abandoned its role in supporting the broad portfolio of civil space applications, and the space technology base has thus been allowed to erode and is now deficient. The former NASA advanced technology development program no longer exists. Most of what remained was moved to the Constellation Program and has become oriented largely to risk reduction supporting the ongoing internal development program. Elements of that former advanced technology R&D focused on space science missions—primarily advanced instrument development—was also moved. Although it continues under the science mission directorate, and good work is being done, there is no longer the broader mandate to enhance the technology base and explore breakthrough technology that could possibly transform future science missions by influencing future requirements instead of simply responding to those already established.

The NRC report observed that future U.S. leadership in space requires a foundation of sustained technology advances that can enable the development of more capable, reliable, and lower-cost spacecraft and launch vehicles to achieve space program goals. A strong advanced technology development foundation is needed also to enhance technology readiness of new missions, mitigate their technological risks, improve the quality of cost estimates, and thereby contribute to better overall mission cost management. Space research and development efforts can take advantage of advances from other fields—and can contribute back to those fields. For example, civil space programs can benefit from and contribute to the state of the art in advanced materials, computational design and modeling, batteries and other energy storage devices, fuel-cell and compact nuclear power systems, fault-tolerant electronics and software, optics, and robotics. This scientific synergy extends the ability to accomplish more capable and dramatic missions in space, as well as to contribute to broader national interests driving innovation in other areas of terrestrial application. The unique challenges of the space environment make demands on technology in ways that often accelerate the development pace and advance understanding of the foundations of technologies. The responsibility to provide for this advanced technology base for civil space activities rests with NASA, in partnership with universities, other government agencies, and industry. The "customers" for the products of technology are NASA, NOAA, industry, and military space programs in which multiple-use technology is applicable.

To fulfill NASA's broader mandate, the study concluded that an independent advanced technology development effort is required, much like that accomplished by DARPA in the DOD, focused not so much on technology that today's program managers require, but on what future program managers would wish they could have if they knew they needed it, or would want if they knew they could have it. This effort should engage the best science and engineering talent in the country wherever it resides in universities, industry, NASA centers, or other government laboratories independent of pressures to sustain competency at the NASA centers. A DARPA-like organization established within NASA should report to NASA's Administrator, be independent of ongoing NASA development programs, and focus on supporting the broad civil space portfolio through the competitive funding of world-class technology and innovation projects at universities, industry, federally-funded research and development centers, government research laboratories, and NASA centers. The responsibilities of the organization should be similar to those of NASA's aeronautics research in the sense that the research activities should be supportive of the needs of the private sector as well as the government—a mission well understood and supported by NASA going back to its predecessor, NACA.

Establishing an independent organization focused on broadly enhancing the technology base for civil and commercial space does not mean the development programs and operational mission areas of NASA do not need their own technology research and development resources to mature technology ready for transition and for risk reduction. Furthermore, a technology management process is needed that draws the interests of all stakeholders to common ground to assure the investment in technology is relevant to the needs of the eventual users and that a plan exists for its transition. This process creates a healthy tension between technology push and user pull.

The DARPA-like reference is not to be taken too literally, since what works well in the Department of Defense needs to be adapted to the NASA culture. But the reason for the reference is to address the need for an advanced technology mission to be given priority, be organizationally independent, be authorized to pursue technical excellence and research quality wherever it resides relieved of NASA institutional requirements, and be encouraged to promote and sponsor transformational, game-changing innovation that is not necessarily formally tied to existing, well-defined requirements.

The country expects NASA to be a leader pushing the frontiers of air and space applications and missions as called for in the Space Act. But to do so, they need to replenish the underpinning technology that makes it possible. I believe it is time to make technology research and development an explicit priority as part of the agency's broader mission.

Thank you. That completes my prepared remarks and I would be pleased to take questions you may have.

Biography for Raymond S. Colladay

RAYMOND S. COLLADAY is a retired corporate officer of the Lockheed Martin Corporation and the former President of the Lockheed Martin Astronautics company in Denver. Before entering the private sector, he held positions of Director of DARPA—the Defense Advanced Research Projects Agency of the U.S. Department of Defense and was Associate Administrator of NASA where he had senior executive responsibility for the agency's aeronautics and space research and technology development including operations oversight of Ames, Langley, Dryden, and Glenn Research Centers. Dr. Colladay started his aerospace career at NASA Glenn Research Center in propulsion R&D before moving to NASA Headquarters where he held a number of leadership positions before being appointed Associate Administrator of the Office of Aeronautics and Space Technology. He has been a member of the Air Force Scientific Advisory Board and various Defense Science Board summer studies. Currently, he owns an aerospace consulting company, RC Space Enterprises, Inc.;

teaches leadership and ethics for the Colorado School of Mines; and serves on a number of boards, steering committees, and commissions. He received his B.S., M.S., and Ph.D. degrees in mechanical engineering from Michigan State University and attended the Harvard Business School's Advanced Management Program. He is a fellow of the AIAA and of the American Astronautical Society. Dr. Colladay is Chairman of the Aeronautics and Space Engineering Board (ASEB) of the National Academies. He has two daughters and four grandchildren and resides in Golden, Colorado with his wife of 44 years.

Chairwoman GIFFORDS. Thank you, Dr. Colladay.
Mr. Scolese.

STATEMENT OF MR. CHRISTOPHER SCOLESE, ASSOCIATE ADMINISTRATOR, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. SCOLESE. Chairwoman Giffords, Ranking Member Olson, and members of the subcommittee, thank you for the opportunity to appear today to discuss NASA's technology development programs.

NASA has been at the forefront of aeronautics and space research since the early 20th century. The complex research missions that NASA is asked to do to explore the unknown serve as stimulus to innovation. As a result, NASA and its predecessor, NACA, traditionally balanced our technology activities to meet both the needs of our near-term missions and our long-term plans.

Recent National Academy reviews of NASA innovation and technology development endorsed increased emphasis on innovative technologies and approaches to achieving broadly defined NASA and national goals. These reports and others suggested that NASA should increase emphasis first in disruptive or game-changing technology, and second in maturing technologies for flight.

In answers to the subcommittee's question about the timeframe for technology investment, NASA believes the timeframe from these early technology activities should be long enough to allow for revolutionary impact, yet not too long so as to mask clear applicability to NASA or national needs or in the 10 to 20-year timeframe. Managing all of the investment areas will require a hybrid of management processes, with strong agency-wide planning and coordination. One size does not fit all.

Mission directorate investments focused on mission needs will be best managed within those directorates. Early-stage innovation, disruptive, and strongly-crossed cutting investments are best served by an independent management structure still responsive to the needs of the mission.

With regard to the committee's question on authorization legislation directing greater commitment to robust technology research and development initiatives, three examples stand out. In aeronautics we formulated the new environmentally-responsible aviation project to develop technologies related to improving the air space system to be more environmentally friendly. Multiple collaborations are underway with other federal agencies and private entities to make use of the space station as a national laboratory. And in science the most recent annual competitions for instrument technology development emphasized cross-cutting technologies.

The subcommittee asked how NASA develops and infused game-changing technology solutions without a dedicated long-term technology program. NASA does invest in a limited number of game-changing technologies through its innovative partnership program and within our mission and engineering organizations. Examples include optical communications and large pressurized composite structures. NASA routinely coordinates with other federal agencies to develop technologies and concepts of mutual interest.

The NASA aeronautics research portfolio is strongly aligned with the National Aeronautics R&D policy and plan and the high-level goals of the NRC decadal survey. And as mentioned, the Space Station National Laboratory has been made available to other U.S. government agencies, academic institutions, private firms, and non-profit institutions.

For example, NASA funded approximately 250 investigations related to ISS [International Space Station] life science research and exploration, many of which leveraged additional funding from the National Science Foundation, the National Institute of Health, the Department of Defense, and the Department of Energy. Our Nation has made great progress throughout its history because of the enormously difficult challenges it has embraced. The grand challenge to build an intercontinental railway or the Apollo Lunar Program not only utilized our best talent but also created new technologies, inspired generations to pursue challenging goals, created new industries, and ultimately improved our country and the world. Similar opportunities are in front of us now, and NASA most assuredly can contribute.

Chairwoman Giffords, I would be happy to respond to any questions you or the other members of the subcommittee may have.

[The prepared statement of Mr. Scolese follows:]

PREPARED STATEMENT OF CHRISTOPHER SCOLESE

Chairwoman Giffords and other Members of the Subcommittee, thank you for the opportunity to appear today to discuss NASA's technology development programs. As a research and development Agency, a balanced portfolio of R&D at NASA serves the Nation directly and is a catalyst for innovation as well. My testimony will address how NASA technology is relevant to the Nation and the communities that comprise it, and how that might be strengthened.

In your letter inviting me to testify, you asked that I address a number of specific questions related to technology development at NASA. My statement will address those questions, as well as provide additional context.

NASA has been at the forefront of aeronautics research and development since the early 20th Century, and space technology since the mid 20th Century. During that time, NASA and its predecessor organization, the National Advisory Committee for Aeronautics (NACA), balanced near-term missions and long-term research to benefit the Nation and the world. Over the past few years, however, NASA has prioritized short-term mission needs over long-term research. Much new technology in terms of materials, systems, components, and software that benefits our missions as well as others is developed through the NASA Mission Directorates, the Innovative Partnerships Program, and the Centers. The NASA mission focus also serves technology development by focusing activities on technologies needed to address current and future problems as well as providing the test bed for demonstrating these new technologies.

NASA Response to Recent External Reviews

Several recent external reviews have addressed the issues of innovation and technology development at NASA, with a strikingly common set of themes. Although the final report is still pending, the Summary Report of the Review of U.S. Human Space Flight Plans Committee strongly endorsed increased focus on innovative technologies and approaches to achieving broadly defined NASA and national goals. This technology and innovation focus was included in all new program options suggested by the Committee in its Summary Report. The recently released National Research Council (NRC) report, *"America's Future in Space,"* specifically calls for NASA to create a capability to develop game changing approaches to National challenges. This recommendation is similar to one made by the Aldridge commission in 2004. Finally, the recent NRC report *"Fostering Visions for the Future: A Review of the NASA Institute for Advanced Concepts"* is also highly relevant. It suggests re-creating an early stage innovation engine like the NASA Institute for Advanced Concepts (NIAC). These NRC reports especially emphasize the need for some organizational independence from the mission-focused parts of the agency in order to provide stability to the investment and a more risk-tolerant environment to foster innovation. They recommend a broad reach, across disciplines and organizations, to ensure the best ideas are brought forth and supported. All suggest that failure to invest in technology and innovation puts the Agency's future viability at great risk.

In recognition of the need to rebalance near-term mission and far-term technology and innovation investments, the Agency chartered an internal study team to investigate the barriers to NASA innovation and make suggestions for approaches to address these barriers. The study team had participation from across NASA Mission Directorates, Centers, and Offices.

The barriers to innovation identified by our internal study team agree with many of the findings of the external committee reports with respect to both the overall shortfall and the focus. NASA's investments in innovation and technology have been focused on the near term, especially in the space-related disciplines. In addition, the Agency could do a better job in many areas of engaging partners from across academia, industry and other Government agencies in its technology development efforts. This would allow both the most innovative ideas to be brought forward, and the broadest application of NASA-supported capabilities to address broader National needs in areas of high priority to the Nation.

Also recognized in multiple studies is the importance of capabilities for taking technology from the lab bench to demonstration for flight use. This is an area which has traditionally been left to flight projects which typically cannot assume the risk and/or cost for technologies that are not enabling the mission, and requires a diversity of approaches to ensure that the needs of the ultimate user community are fully addressed. Driven by the specifics of the technology and the target use, successful approaches can be as simple as environmental and life testing or as complex as demonstration packages on host missions or dedicated flight demonstrations.

NASA is planning to use an integrated portfolio management approach, balancing needs from across the Agency, balancing near-term and long-term investments, and ensuring that resources are appropriately leveraged across the various mission areas to secure the maximum impact for our investments. NASA will examine reward structures and culture to encourage more risk-taking in innovation activities. Although our "failure is not an option" ethic is essential in the spaceflight arena where lives are at stake, innovation demands pushing the envelope, occasionally failing, and learning from those failures to drive game-changing solutions to NASA's grand challenges.

NASA Missions Require Technology to Address Extreme Conditions

NASA's missions require technology beyond state-of-the-art, where hardware and systems meet the extreme conditions of space and high-performance aeronautics. The environments in which humans, spacecraft, and equipment must work pose unique challenges, prompting development of unique capabilities.

Science missions face a variety of extreme environments, with over 90 spacecraft operating or planned to operate throughout the solar system and beyond. For example, the Juno spacecraft being prepared for launch in 2011 must survive a five-year journey to Jupiter and operate for about a year on solar power in an area where there is 25 times less sunlight than at Earth and at temperatures that may approach −275 degrees Fahrenheit, requiring some of the most hardy and efficient solar arrays ever built. The James Webb Space Telescope, a 6.5-meter (~21 feet) space telescope, will need to operate at about 35 degrees above absolute zero or −396 degrees Fahrenheit. Another example is Solar Probe Plus, which is planned to launch no later than 2018 and will operate just 3.7 million miles above the Sun's "surface," some seven times closer than any spacecraft has come before. At its closest approach, Solar Probe Plus' shield must withstand temperatures up to 2,600 degrees Fahrenheit, while allowing the payload of science instruments to operate at or near room temperature.

While more protected inside the Earth's magnetic field, NASA and its partners must enable humans to live and conduct experiments in space on the International Space Station—a 500 metric ton, football-field sized, permanently crewed, full-service space platform operating at an altitude of 350 kilometers in a 51.6 degree inclination to the Earth's equator. Research for flight beyond low-Earth orbit must enable long-term human health in micro-gravity, under varying radiation conditions, with remote medical assistance. Lastly, although operating on Earth, aeronautics research must make air vehicle concepts, such as vertical lift and supersonic flight practical for commercial use, and enable significant increases in air transportation capacity while still protecting the environment, ensuring safety, dramatically improving efficiency, and revolutionizing the flow of air traffic.

Relevance of Mission Technology to other Sectors

NASA technology development over the last decade has by and large focused on the needs of the missions. This situation raised the importance of infusion into NASA missions of technology developed jointly in partnerships with industry, academia, other Federal agencies, and other external entities. Interestingly, the advanced nature of NASA technology, combined with the emphasis on partnering, served to increase the likelihood of additional relevance to other market sectors and communities.

As an example, the Science Mission Directorate (SMD) partners with the Small Business Innovative Research (SBIR) program to develop key technologies for the Mars Science Laboratory (MSL). SMD worked with Microwave Power Technology of Campbell, California, to develop a small-format Carbon Nanotube Field Emission cathode (CNTFE) X-ray tube for the Chemistry & Mineralogy instrument on MSL. While a tungsten cathode was ultimately baselined for the flight tube, the form, fit and function of the flight tube was derived from this SBIR project.

The Innovative Partnerships Program works through its offices at all ten field centers to facilitate the transfer of Agency-developed technologies for commercial application and other public benefits. Licensing, together with a wide portfolio of innovative partnering mechanisms, results in commercial products that contribute to the development of services and technologies in health and medicine, transportation, public safety, consumer goods, agriculture, environmental resources, computer technology, manufacturing, and other key industrial sectors. Each year, NASA documents 40-50 of the best current examples of how mission technology has yielded public benefit in the annual *Spinoff* publication.

Game-Changing or Paradigm Shifting Solutions

Due to the near-term program focus of NASA's current technology programs, the likelihood of developing and infusing mission "game-changing" technology is reduced. Still, with clear challenges on the demand-side, significant emphasis on partnering, and continuing programs with universities, such paradigm-shifting solutions do nonetheless occur, often with additional applicability outside of NASA.

NASA's Exploration Systems Mission Directorate (ESMD) is developing very high-performance lithium ion battery cells that significantly exceed current state-of-the-art, and are highly reliable, self-contained Proton Exchange Membrane (PEM) regenerative fuel cells. Current automotive fuel cells are not regenerative and consume oxygen from the atmosphere plus hydrogen from onboard storage tanks to generate electricity. The PEM regenerative cell uses electricity to convert water into hydrogen and oxygen stored in tanks that can later be reconverted back into electricity. In space applications, such advances in energy storage systems would be useful to human explorers on a terrestrial surface where there is a decreased ability to create solar energy. This technology also could be useful to farms and businesses that need large kilowatt power generated during off-peak hours on the grid or from other sources.

The NASA partnership with the Defense Advanced Research Projects Agency (DARPA), industry, universities, the Internet Research Task Force and several international space agencies has created the new technology of "Delay Tolerant Networking" (DTN), which enables the extension of the Earth's Internet to sustain communications over interplanetary distances—for example to and from the Moon and Mars. This technology has been spun-off to enable many new terrestrial applications where the Internet can be extended into highly stressed communications environments, such as remote villages, battery-powered sensor webs and undersea communications. Military applications of DTN are substantial, allowing the dissemination of critical battlefield situational awareness information into areas where communications networks are sparse and subject to a high degree of disruption.

NASA, in partnership with the Air Force Research Lab and Boeing, successfully completed flight experiments of the X–48B Blended Wing Body (BWB) advanced aircraft at the NASA Dryden Flight Research Center. The BWB is a hybrid configuration combining the best attributes of a conventional "tube-and-wing" aircraft with a flying wing. It has the potential to meet expected future Next Generation Air

Transportation System requirements for low noise, low emissions, and high efficiency. It is the first time a dynamically scaled BWB was flown. The experiments demonstrated the basic flying qualities of the X–48B and the effectiveness of the onboard flight control system. NASA is continuing to research the BWB concept along with other unique configurations in order to enable future vehicles that profoundly improve the efficiency and capabilities of air transportation.

Other examples include optical communications, in-space propulsion, and tools and techniques such as modeling and simulation for Earth science, or shell buckling test facility and analysis for significantly reduced weight and cost of next-generation launch vehicles. A program similar to the NASA Institute for Advanced Concepts (MIAC) would be valuable in identifying other game changing technologies.

Technology Innovation and Leveraging

The NASA Innovation Partnerships Program (IPP) continues to pioneer the use of non-traditional approaches such as the Centennial Challenges Program which uses incentive prizes to spark innovation and drive technology to meet the Agency's high-performance technology challenges. A key result of the Centennial Challenges competitions is the demonstration of dramatic efficiencies in the research and development process when compared with typical industry practices.

The Lunar Lander Challenge requires that teams build and fly a reusable rocket-powered vehicle that can mimic a robotic flight to and from the surface of the moon, but in an Earth-based demonstration. Teams must design, build and test these vehicles without any government support or funding. The return on investment with an incentive prize can be enormous, and this contest has yielded working prototypes from multiple sources. Two teams have successfully flown vehicles and qualified for prizes and others are planning to fly later this month. Additional NASA partnerships and commercial ventures have resulted from this incentive prize.

Another example is the Regolith Excavation Challenge which recently took place at Moffett Field in California. The goal was to use either a teleoperated or autonomous device to excavate at least 150 kilograms of simulated lunar regolith within thirty minutes. Nineteen teams competed with working robots, and three teams met the minimum requirements and claimed prize money, with the winning team from Worcester Polytechnic Institute excavating over 500 kilograms. The Regolith Excavation Challenge is important because future lunar astronauts may "live off the land" by excavating lunar regolith and extracting useful materials from it, such as oxygen and even recently discovered water molecules that seem to be bound within lunar topsoil. The competing teams advanced the technology necessary for this kind of operation without a lot of investment from NASA.

Additionally, the NASA IPP Partnership Seed Fund enhances the Agency's ability to meet mission technology goals by providing seed funding to overcome technical barriers with cost-shared, joint-development partnerships between non-NASA partners, NASA Programs and Projects and NASA Centers. Seed Fund projects have highly leveraged NASA's investment and resulted in many important technologies including: two different lunar tire designs from partnerships with Michelin and Goodyear; a prototype inflatable lunar habitat that was field tested in Antarctica in partnership with the National Science Foundation and ILC Dover; and testing of alternative fuels for aircraft engines in partnership with Pratt & Whitney and the Air Force Research Laboratory.

Coordination and Collaboration with Partners

NASA and its partners leverage mutual interest in many technologies across the missions. For example, ESMD has a research portfolio related to its Exploration Technology Development Program and Human Research Program that will benefit future space explorers as well as other organizations on Earth. NASA is funding approximately 250 investigations related to ISS research and exploration that include approximately 80 active flight investigations. Investigators in the life sciences do not depend solely on NASA for the totality of their research funding. Most NASA funded investigators receive funding from other agencies as well, including the National Science Foundation, the National Institute of Health, the Department of Defense, and the Department of Energy for related research efforts. In fact, NASA often works directly with these agencies through working groups and Space Act Agreements. The ESMD has nearly 100 agreements in the form of Memoranda of Agreement and Understanding with other Federal agencies and international partners. The synergy between these Federal agencies is clear and coordinated.

In FY 2008, about half of SMD's investment in technology programs was in mission-specific technology developments tied to NASA flight missions. The remainder was for Principal Investigator-led research investigations, suborbital research programs (which are often used to test new technologies and instruments in suborbital context before they are manifested on space-borne missions), and a dedicated Earth science technology program to enable the highest priority missions called for in the National Research Council Earth Science Decadal Survey. These latter investments supported 21 instrument incubation projects that are broadly aimed at addressing science measurement objectives put forward in the Earth Science Decadal Survey. These new projects include a carbon dioxide (CO_2) laser sounder for the Active Sensing of CO_2 Emission over Nights, Days, and Seasons (ASENDS) mission (a Tier 2 mission in the decadal survey), a multi-parameter atmospheric profiling radar for the Aerosol/Cloud/Ecocsystems (ACE) mission (a Tier 2 mission) and a laser ranging frequency stabilization subsystem for the follow-on Gravity Recovery and Climate Experiment (GRACE–II) mission (a Tier 3 mission). These Earth Science measurements will enable us to better understand how the Earth's climate, water cycle, carbon cycle, and living beings interact and how they impact society.

NASA also works with industry partners who can adapt these technologies to serve broader societal needs. Perhaps the world's most famous telescope, the Hubble Space Telescope has given us more than close-up views of our galaxy; it has served as a technological engine for various industries. Technologies developed for Hubble have enabled surgeons to perform micro-invasive arthroscopic surgery with increased precision, made breast biopsies less invasive and more accurate using imaging technology, and led to optimized semiconductor manufacturing through precision optics and advanced scheduling software.

As NASA transitions the ISS from the assembly phase to the full utilization phase, the ISS will be operated as a U.S. National Laboratory and thus made available to other U.S. government agencies, academic institutions, private firms and non-profit organizations. At that stage, the research benefits will extend beyond NASA and begin accruing in areas related to U.S. national needs in such areas as improvement in human health and energy systems research.

Improvement in human health is the mission of the National Institute of Health (NIH). The NIH entered into a Memorandum of Understanding with NASA to use the ISS for research. In Spring 2009, NTH issued a three-year rolling announcement for research grants in areas including: (I) cancer; (2) heart, lung and blood disorders; (3) aging; (4) arthritis and musculoskeletal and skin diseases; (5) biomedical imaging and bioengineering; (6) child health and human development; and, (7) neurological disorders and stroke. Research is scheduled to begin by the end of 2010.

In preparation for full utilization phase of the Space Station, NASA has entered into agreements with private firms such as Astrogenetix, Inc. as pathfinders for the future. Based on basic research funded by NASA under prior grants, the company is now pursing vaccine development under microgravity conditions. A vaccine target for salmonella-induced food poisoning was discovered in 2009, and the company is seeking investigational new drug status from the U.S. Food and Drug Administration. Follow-on experiments are underway on a variety of bacterial pathogens, including Methicillin Resistant Staphylococcus Aureas (MRSA), which is responsible for, almost 20,000 human deaths per year.

The NASA Aeronautics Research Mission Directorate (ARMD) has a research portfolio, predominately focused on long-term foundational research, which is both comprehensive and coordinated in order to make substantial improvements to the future air transportation system. There is strong alignment of NASA's aeronautics research portfolio with the National Aeronautics Research and Development Policy and Plan and the high level goals of the National Research Council's Decadal Survey on Civil Aeronautics (2006), which identify short and long-term strategic aeronautics research and technology goals for our Nation. A good example is the development of new vehicle concepts that are much more efficient and exhibit dramatic reductions of emissions and noise impacts. NASA fundamental research has paved the way for concepts such as hybrid wing body vehicles that are quite different from the "tube and wing" aircraft that are familiar today. Research includes novel propulsion systems and support for the creation of new alternative fuels that show promise for even more improved environmentally friendly performance.

Similar to the other Mission Directorates, ARMD utilizes a variety of mechanisms to engage academia and industry, including industry working groups and technical interchange meetings at the program and project level, Space Act Agreements for cooperative partnerships with industry, and the NASA Research Announcement (NRA) process that provides full and open competition for the best and most promising research ideas. Cooperative partnerships with industry consortia result in significant leveraging of resources for all partners and can provide opportunities to test the value of component-technology advances in full system-level contexts. All research results, whether generated by NASA internally or by its partners through the NRA, are openly disseminated through archival publications and conference proceedings as well as NASA publications to benefit the broad U.S. aeronautics community while ensuring the dissemination policy is consistent with National security and foreign policy guidelines.

NASA aeronautics research is conducted in a highly collaborative environment among Federal agencies. The National Aeronautics Research and Development Policy and Plan provides the strategic framework that facilitates coordination among the Federal agencies. NASA builds upon this framework to coordinate with other Agencies when appropriate. For example, to facilitate the transition of advanced ideas and technologies into the aircraft fleet, NASA is partnering with the Federal Aviation Administration's Continuous Low Emissions, Energy and Noise (CLEEN) program to guide efforts to mature technologies that have already shown promise to the point where they can be adopted by the current and future aircraft fleet. Additionally, NASA and the U.S. Air Force have established an Executive Research Council that meets at least twice a year to ensure close coordination and collaboration. Another example of a significant partnership effort involving NASA that spans multiple government and commercial organizations is the Commercial Aviation Safety Team, which was recently honored with the prestigious Collier Trophy for reducing fatal air transport accidents by 83 percent in a decade.

Response to NASA Authorization Act Direction Related to Technology Development

With regard to NASA's response to the provisions in authorization legislation directing greater commitment to robust technology research and development initiatives in aeronautics, exploration, and space and Earth sciences, several examples stand out.

NASA has responded to authorization language pertaining to further investment in the development of technologies related to environmentally friendly aircraft by formulating the new Environmentally Responsible Aviation Project under the new Integrated Systems Research Program in order to build on recent developments in the existing research programs. This new effort will include further technology advancement and research in conjunction with academic and commercial partners. Work is also ongoing to ensure that new vehicles are accurately modeled in air traffic management simulations, but further research can improve the fidelity of these simulations to facilitate the development of new procedures, processes and techniques for managing air traffic.

While NASA-sponsored investigations on the Space Station are currently focused largely on enabling future long-duration human space exploration missions, Congress designated the U.S. portion of the Space Station as a National Laboratory making its facilities available to other federal agencies and private entities. These collaborations are well underway.

In addition to non-mission focused technology activities previously mentioned, NASA's Science program continues to emphasize the role of cross-cutting technologies in the annual competitions for its major technology development programs such as the Planetary Instrument Definition and Development Program and the Earth Science Instrument Incubator Program. We have already conducted a review to determine the highest-priority, cross-cutting technologies, and we will use those priorities in making future selection decisions for technologies. Key cross-cutting technologies of interest to science include sensors (e.g., Light Detection and Ranging LIDARs, long-life lasers, in situ sensors and tools), information systems (e.g., data processing, large-scale numerical simulation/modeling, and data management, mining and visualization tools), platforms (e.g., photovoltaic and radioisotope power systems, chemical and electrical propulsion, radiation-hardened computer processors, low power/low mass application-specific integrated circuits), suborbital technologies (including sounding rockets, balloons, and unmanned aircraft systems), large lightweight deployable structures (especially telescopes and antennas), and integrated modeling techniques (e.g., structural, optical, thermal, and instrument models that share the same databases).

Conclusion

The National Academy of Sciences issued a warning in its report *Rising Above the Gathering Storm:* "The United States faces an enormous challenge because of the disparity it faces in labor costs. Science and technology provide the opportunity to overcome that disparity by creating scientists and engineers with the ability to create entire new industries—much as has been done in the past." The Academy recommended increasing America's talent pool by vastly improving K–12 mathematics and science education; strengthening the Nation's commitment to long-term basic research; developing top students, scientists, and engineers; and, ensuring that the United States is the premier nation in the world for innovation.

Most assuredly, NASA can contribute. As the Agency pursues demanding missions in Earth science and climate research, human and robotic exploration, astronomy and astrophysics, solar physics, and aeronautics, NASA must answer several fundamental questions: Is there water on Mars? Can humans live for extended periods in space, and if so can they live on the resources they find? What can we do to inform choices on mitigating and adapting to global change? Are there other solar systems like ours in the universe? As noted earlier, the missions created to answer those questions utilize specialized hardware that must endure extreme environmental conditions and demand functionality beyond that required for Earth-based applications.

The NASA mission focus and ability to develop technology from infancy to application provides an extraordinary forcing function for innovation. The Agency's technology challenges are multidimensional, requiring multidisciplinary solutions. Shared with the academic community, these challenges help prepare graduate students by enabling them to work on real-world challenges early in their careers. NASA technology lends itself to practical collaboration across government, academia, and industry. In addition, technology development linked to exciting NASA missions can provide a low risk avenue to encourage K–12 students. Finally, most NASA projects require large-scale system engineering. Addressing challenges with these characteristics has a powerful galvanizing effect on educational institutions and students, and thus on the aerospace industry, other industries, and on NASA.

Our Nation has made great progress throughout its history because of the enormously difficult challenges it has encountered. The grand challenge to build an intercontinental railway, or to land a man on the Moon and return him safely to the Earth, not only utilized our best talent, but also created new technologies, inspired generations to pursue challenging goals, created new industries, and ultimately improved our country and the world. Similar opportunities are in front of us now.

Chairwoman Giffords, I would be happy to respond to any questions you or the other Members of the Subcommittee may have.

Chairwoman GIFFORDS. Thank you. At this point we are going to start our first round of questions, and the Chair recognizes herself for 5 minutes.

I would like to start with Mr. Scolese. You have heard testimony from the other panelists about some—the recommendations of why this is important and the suggestions that this really matters, and it needs to be reinstituted. We have heard about the importance of advanced technology development at NASA, but could you speak more specifically about the attributes of such a program? How would NASA structure a short-term, a mid-term, and a long-range term program in terms of the needs of the agency and its various mission directorates?

And also, should we expect to see any changes in NASA's technology development programs in the fiscal year 2011 budget?

PROGRAM ATTRIBUTES

Mr. SCOLESE. Certainly. In terms of the short-term technologies and even the mid-term technologies we have our programs largely aligned with our missions. So they tend to stay within the mission directorates, and those are moving along fairly well.

As an example, in the science mission directorate we invest about 10 percent of their budget in technology development. That is where we go off and look at the instruments that we may need in the future or entry descent and landing as Dr. Braun mentioned earlier for going to Mars with different payloads. So for those, as I mentioned in my testimony, we would expect those to stay within the mission directorates.

The longer-term technologies, typically we would like to look at things that are cross-cutting, that could affect more than one mission area; aeronautics, science, or human spaceflight programs. Those don't tend to fit well within a mission directorate, and we would think that if we went off to do those, we would take a step back and look at a more coordinated process across our directorates. Whether that would be as Dr. Colladay mentioned an entity that reported to the administrator or it would be put into some other organization, I couldn't say at this time.

And to your last question or last part of the question, earlier this year we recognized and we recognized before that our investments in technology have changed. They have changed their focus to a more near-term focus as opposed to the longer-term focus for a variety of reasons. So we asked a team to go off and look at what we could do.

So, yes, I will, you will—can expect to see some changes in how NASA does technology in the future.

Chairwoman GIFFORDS. The next question I have is something that is based on what our recent new administrator said to the general public, and he said that the President tasked him to make NASA inspire young people again, and in that same vein NRC's report on the NIAC basically went on to talk about that role of NASA's importance for inspiring the public with a spirit of discovery and exploration.

So I guess I would like to start with Dr. Braun. If you could elaborate on your committee's work in terms of what you regard as inspirational, educational, the contributions that NIAC has made and then turning to Mr. Scolese, I would like to hear some of the elements in this technology program that we could pull that in, and of course, from Dr. Colladay as well.

PUBLIC RELATIONS/STUDENT RELATIONS

Mr. BRAUN. Okay. In addition to the work that was funded directly by NIAC with the external innovators, NIAC did have a student fellows program and also was very visible in a public outreach campaign. So to address your question directly I think our committee felt that NIAC did an excellent job of actually earning positive public support for NASA through its actions and of inspiring students actually around the country to be a little more creative and to think outside the box. So that was certainly true.

In—if I could add one other point, in my discussions with students on campus, you know, that occurs most days, you know, when I am not here in Washington, DC, students are really interested in the future much farther beyond say the next 5 or 10 years in general. You know, they are people that are about to enter the workforce, and they are going to be in the workforce for 20 to 40 years, and so visionary, far-reaching technology programs, innovation and creativity are things that pull them into engineering and science in general. Thank you.

Chairwoman GIFFORDS. Mr. Scolese.

Mr. SCOLESE. Well, I would agree with all of that. Engineers and scientists want to think about the future, and they want to work on things for the future. So our missions automatically inspire people to want to go off and do that.

But specifically some things that we are doing today to help work that is we have a suborbital program with sounding rockets and balloons as an example. It is not strictly the technology part, but it gives students and graduate students, undergraduate students an opportunity to develop and experiment, test it in a real flight-type environment where there isn't the overwhelming pressure to succeed as you would have with a mission. So we find those opportunities and in any technology program we would do, we want to engage, and in fact, any technology program we do today we do engage universities as well as industry, but in particular the universities to get the graduate students and then undergraduate students engaged in these activities. And in some cases even high school students.

Chairwoman GIFFORDS. Dr. Colladay.

Mr. COLLADAY. NASA has a mission that in itself excites people, and so in many respects you have one of the easiest jobs I can imagine to generate the kind of enthusiasm that will lead people into engineering careers and science careers.

There is two things that—and it starts very early. There is two—at a young age. There is two things that seem to be in our genetic wiring. Kids love dinosaurs, and they love space, and NASA can really capture the interest in space because they have real interesting problems to solve. And in many respects defining those problems and then translating them into technical solutions is what engineering students and scientists like to wrestle with.

So I think the mission is there to generate that kind of excitement.

Chairwoman GIFFORDS. Thank you, Dr. Colladay.

The Chair is going to recognize Mr. Olson.

Mr. OLSON. Thank you, Madam Chairwoman. I have a question for Dr. Braun and Dr. Colladay.

Your report provides good insight into the demise of NIAC, but given its unique roll and relatively small cost why was NASA so indifferent about NIAC's fortunes? Why was it allowed to close? Where were its advocates, and why did they fail?

COLLAPSE OF NIAC

Mr. BRAUN. Well, I can only give you my opinion on that, and I am happy to do so. I, of course, wasn't in NASA at the time. What happened with the NIAC is that it was envisioned originally as a cross-cutting program outside the mission directorates that was seeking advanced technology and infusing them into NASA's missions.

With the dissolution of the aerospace technology enterprise at NASA, the former Code R in 2004, NIAC got moved into the exploration systems mission directorate, and shortly after that with the budget crunch if you, you know, to use my words, with the budget crunch to get the Constellation program going and getting humans back to the moon, a pretty strong effort was made throughout the agency to squeeze down and remove many of the technology development programs. Not just the NIAC. Nobody—I am fairly certain that nobody within NASA went directly after the little $4 million NIAC Program, but in sweeping out a lot of these larger technology programs, NIAC was also removed in 2007.

Mr. OLSON. Dr. Colladay.

Mr. COLLADAY. Well, I would agree with that observation. I would also say that protecting the resources for really innovative, far-term, advanced technology requires a champion. It requires a person that has enough stature at the table in the budget battles that come every year to defend that investment, because at the end of the day it is a good-faith investment in the future. And if that advocate, that champion for advanced technology isn't at the table, it is pretty hard in budget crunch time with scarce resources as NASA has faced over the recent years to defend a program, even though it is only $4 million. It is—every little bit is important.

Mr. OLSON. Thank you for those answers, and I have a question for you, Mr. Scolese. In your statement you highlight a number of technology development activities ongoing across the agency's mission directorate, but I notice there were no mention of Ares, Orion, or Constellation. And for the record could you describe two or three technology development activities associated with our future manned spaceflight program?

MANNED SPACEFLIGHT

Mr. SCOLESE. Certainly. There is actually a number of activities that are in what we term our Exploration Systems Mission Directorate, which is where the Constellation Program is with Orion and Ares and the ground systems that support that. Some of the far-reaching technologies that we are looking at there that can help not only human spaceflight but others, one is a composite crew module, and that may sound a little different, but most everything that we have manufactured for human spaceflight has been made out of metallics; aluminum or steel of one type or another. And there is certain benefits if we could go off and use structures that are made out of essentially plastics.

However, we have been using them on the science missions for many years because they give us certain benefits that allow us to make those missions much better, but we haven't applied them broadly to large structures because we haven't been able to find any theory that tells us how to build them.

So we decided that we needed to go off and understand that technology and develop that technology and chose to build a crew module very similar to Orion out of a composite structure. We worked that with all of our NASA centers basically because our science centers have lots of experience with composites. Our Langley Research Center has worked on composite structures for aircraft elements, and Marshall Spaceflight Center has worked on composites for rocket parts. And you can go around to all of our various centers that have analytical techniques, but we needed to be able to go off and build it.

So we went off and worked with industry and academia to build it, test it. It has a pressurized system, and we are in the process now of testing it. The good news is is we are developing a theory. Our tests are now going to see how well we did with that theory. The good news is so far with the initial tests that we have done, theory and application are turning out to match very closely, so that is very good. The applications are probably not for the crew module, probably not for Orion, but downstream if we went to send people to Mars or the moon or libration points, wherever it may be, will allow us to make structures that are more efficient, perhaps lighter, and better understood.

It has commercial applications. Already the aircraft industry is looking at what we are doing and talking about large fuselage as opposed to just segments of the fuselage or the wings. So it has proven to have a very—it is a very good technology.

Another area to follow on with what Dr. Braun said, is going to Mars. Ultimately we want to send humans to Mars, and as Dr. Braun said, all of our technology is based on the 1970s when we went off and did Viking. The Mars Science Lab is the largest thing we are going to land on Mars, and we are struggling with the fundamental physics of being able to get that done.

So what we have done partnering with all of our mission directorates is we have instrumented that spacecraft so that we can get some really good data finally on the atmospheric profile and what actually happens as we are descending through that—the Martian atmosphere.

In addition, if you look at MSL, it is about the same size as the Orion capsule. So we are also going to use that in helping to improve the design of the Orion capsule as well.

So those are just two examples of what we are doing in or associated with the Constellation program.

Mr. OLSON. Thanks for that answer. I mean, those are pretty impressive examples of what we are doing with that technology.

And finally I would just like to close, one question for all of you. What percentage of the NASA budget should be devoted to non-mission-oriented technology development in your opinion? Humble opinions?

NON-MISSION BUDGET

Mr. COLLADAY. Somehow I knew that question would come. I have said in a number of different forums that I thought an advanced high-tech agency or any organization with a mission like NASA should fence or protect resources at the level of about 10 percent of the total budget for really advanced, innovative technology development.

Now, the fuzziness comes in how much of that is really near-term, mid-term, and far-term, because technology development needs to be mission specific in the mission directorates as well. But I would say a good starting point in answering that question would be 10 percent of the budget, at least building to that, and that includes aeronautics, too. I mean, I would put the space technology and aeronautics together at 10 percent.

Mr. OLSON. Thank you, Dr. Colladay. Dr. Braun.

Mr. BRAUN. Yeah. Well, I would—I agree completely with Dr. Colladay's assessment. In my written testimony I suggested that at least 10 percent of NASA's budget should support technologies required to dramatically advance entirely new aeronautics and space endeavors. And so the way I view this question is that is 10 percent above and beyond mission-focused technologies. NASA obviously needs to be doing mission-focused technology development work. The examples that Mr. Scolese gave are excellent examples of that, and that work needs to continue.

But in addition to that work, which could be jointly funded by mission directorates and a cross-cutting technology enterprise, in addition to that work something like 10 percent of the agency's budget devoted to new endeavors in aeronautics and space is about right to an agency whose goal is to push the frontier and to be looking at the boundaries. Thank you.

Mr. OLSON. Thank you for that answer, and Mr. Scolese, if you feel comfortable answering the question, we would love to hear it.

Mr. SCOLESE. Well, you know there are certain questions that I have to kind of dance around a little. This is one of them. Clearly it is hard to disagree with what was said. A research organization like NASA is—does need to invest, and we do, and we have to determine those priorities in conjunction with you and the Administration.

What I can say, though, on the very positive side is that in our aeronautics area most of that budget is research and development. You can see that sort of with that figure that was shown earlier.

In our other areas we have to go off and look, and the pressures of the mission often do cause some issues, but that is exactly why we went off earlier this year to start looking at what we can do, how can we organize, and how can we, you know, find a better way to go off and advance technologies.

Mr. OLSON. Thank you very much for your answers, and Mr. Chairman, I yield back my time.

Mr. GRIFFITH. [Presiding] Thank you, Ranking Member Olson, and Congresswoman Fudge, would you have some questions?

Ms. FUDGE. Thank you, Mr. Chairman. I thank all of you for being here today. I just have a couple of questions.

The first one for any of the panel members. NASA's funding for research and technology for spacecraft systems for future missions has been significantly reduced over more than a decade. A summary report of the review of U.S. Human Space Flight Plans Committee stated that investment in a well-designed and adequately-funded space technology program is critical to enable progress in exploration. NASA's science mission also requires significant advancements in spacecraft technology to enable exciting new missions.

What increases in funding in critical areas such as power, propulsion, communication, and other technologies is needed to assure that these technologies are developed to support future missions? And in conjunction with that, how will the research and technology funding be managed and dispersed?

Mr. SCOLESE. Well, I guess I got voted. All of those things are critical for both, as you said, both the human spaceflight and the robotics missions. It is hard to say how much and when. I can tell you that we are looking at all of those areas today and perhaps give some examples in—of what we are doing, and that should probably lead to areas of further investigation.

Clearly in communications we are very limited. We are limited in terrestrial communications because the bandwidth is being used for other services. So we are moving towards optical communications, and in space that is pretty easy. You don't have to worry about an atmosphere, you don't have to worry about clouds. So we are making an investment in optical communications that will allow us to get more data back in a way that will be more stimulating to the public for sure but also get more for the scientific community.

Today at Mars we have a fleet of satellites in orbit around Mars and on the surface, and we cannot bring back all the data because we just do not have enough bandwidth with the RF, with the radio frequency links that we have. So this is an area that we are spending a lot of time in.

Propulsion. If we are ever going to get humans to Mars, if we are ever going to get our probes to the far reaches of the solar system efficiently, we need better propulsion techniques. Some of those we are working on today. Ion propulsion is an area that we are now relying on. We use it from the early days in our communications satellites, but we are now relying on it for space missions. The Dawn Mission that is going to the asteroid belt is entirely dependent on ion propulsion, and that is a very efficient propulsion that is being developed with industry but at principally the Glenn Research Center and Jet Propulsion Laboratory. And it has now been adapted by some universities to go off and do missions.

So those are just a couple of examples, but you are exactly right. We can go further in each of those areas to go off and find newer technologies and developments of technologies that will enable those missions. I could add life support, having humans live—today we have humans that can spend 6 months on orbit at a time, but they are close to earth. If things really get bad for whatever reason, they can come home. When we start sending humans beyond, certainly beyond low-Earth orbit but even beyond the moon, we need to have systems that will keep humans alive and be reliable for hundreds of days to years. And those are technologies that we are all looking at and can do more in.

Ms. FUDGE. Thank you. My last question, NASA's in-house research and technology expertise has been instrumental in both assuring advancement of critical technologies and supporting their demonstration and utilization in NASA missions. These capabilities at NASA centers are essential for effectively managing NASA's technology portfolio.

It is also needed for developing and effectively leading partnerships with industry and universities. What is and can be done further to ensure that these in-house civil service capability is maintained and strengthened, particularly in light of reduced center civil service complement over the past several years and an aging workforce with a high percentage of retirement-eligible personnel?

Mr. SCOLESE. Well, certainly having exciting programs, be they technology or missions, is something that is critical. We believe we have the legislative authorities and the contracting tools to allow us to partner appropriately with industry and some examples you have again on your desk of areas in aeronautics where we have some very strong relationships with companies and other organizations. On those we can generally speak only in terms of the general benefit because those companies want to maintain their competitive advantage.

In the space arena it is a little more obvious because there aren't as many organizations that are involved there. But I think we have some good partnerships there. I think if—further if you look at our

Innovative Partnership Program, what we call IPP, where we do a lot of work with the small business community, we have a lot of examples where we have gone off and actually transitioned the technology to other areas.

One example is an endoscope that is used in heart surgery now is a spin-off of a NASA activity that we went off and worked ultimately with a small business. So those are just some examples of some areas that we can do.

Ms. FUDGE. Thank you, Mr. Chairman.

Mr. GRIFFITH. Mr. Rohrabacher.

Mr. ROHRABACHER. Thank you very much. This is for anyone on the panel here. What is the situation where we are doing research, the Federal Government is paying for this research, and who ends up with the patents for new discoveries?

PATENTS

Mr. SCOLESE. Well, unfortunately, the answer is it depends. The—for things where there is clearly—the government is the lead on it, the government owns the patent on that or the—and of course, the credit for the patent goes to the individual that developed the technology. And depending on the agreements that are made, if it is done in conjunction with a university or if it is in conjunction with an industry, whoever those agreements are worked to and where the majority of the activity comes determines who the patent owner will ultimately be.

BENEFIT TO TAXPAYER

Mr. ROHRABACHER. Do you think that the taxpayers are being well served and represented in those negotiations as to who owns—if we finance research, I mean, the taxpayers finance research. Should we not demand that we have the financial benefit, meaning the patent benefit from financing the research?

Mr. SCOLESE. Well, yes, sir, and that is what I was trying to get at. In some of our cases where we have agreements it is only for them to use our test facilities, not to go off where we are putting in resources, and they may reimburse us for those test facilities.

So that is why I was getting at. It depends if the government funds it, we own the patent. There is no question about that.

Mr. ROHRABACHER. Okay. Good. That is what I needed to know.

Mr. SCOLESE. Yeah.

Mr. ROHRABACHER. It seems to me that would be a source of revenue that we could utilize when we talk about expanding the budget for people. Maybe we could make sure that we are receiving the benefits from that research.

Is there any research being done on the space elevator concept?

SPACE ELEVATOR

Mr. SCOLESE. I would have to answer that one for the record, sir. I don't know at this time. I know that there is a prize—or not a prize. There is a technology activity that would allow that to be proposed to, but I do not know what was proposed this year.

Mr. ROHRABACHER. Okay. Are we—I would imagine we just had a launch and a hit on the moon to find out if there is ice that is—

we could utilize. Do we have research going on to find out if there is ice on the moon, how we can use that ice to further the space program?

FINDING WATER

Mr. SCOLESE. Well, yes, sir, we do, because while we are not as sure about the moon, we are very sure about Mars. We have touched ice on Mars, and we know there is a lot of water there. So we do have activities that are related to what we call in-situ resource utilization, where we can take advantage of the resources that are available to us and then go off and use them. And in the case of water in particular, if we have fuel cells, we separate the water into hydrogen and oxygen and then ultimately combine it to use it either as a rocket fuel or to use it as a fuel to generate electricity.

BEAMING ENERGY

Mr. ROHRABACHER. Right. The—is there much being done on beaming energy, or is that something that we did 10 years ago or 15 years ago and not doing it anymore?

Mr. SCOLESE. We actually have an experiment that we are looking at for doing on the space station to do that. I don't know what the current manifest is, but low-power beaming to get some idea of what we can do there and what the practical limitations are. So it has not gone away. It is—

Mr. ROHRABACHER. Good.

Mr. SCOLESE. —still with us.

Mr. ROHRABACHER. It would seem to me that that is one thing that people just—I have talked about this about 10 years ago I remember, and it just seemed to me to have a lot of potential but a lot of—most other people don't think it has much potential, but if we can beam energy, can we—that could actually enable us to put heavier objects into space because we don't have to carry its own, their own fuel.

Mr. SCOLESE. Yes, sir.

Mr. ROHRABACHER. The—let me see. Got to mention something about children and dinosaurs and space. I have—my wife and I were blessed with triplets 5-1/2 years ago, one boy and two girls. I just wanted to reconfirm that they are excited about dinosaurs and space. So with that said thank you very much.

Mr. GRIFFITH. Congressman, thank you. Congressman Miller. Edwards. Excuse me.

Ms. EDWARDS. Donna Edwards from Maryland. Thank you for your testimony. I actually wanted to follow up on a couple of things.

One is I do think it is—and I appreciate your testimony to—as to the difficulty balancing long and near-term goals, and I guess there is stuff in-between and investments and strategies in those because although I think a lot of the public really thinks about NASA as sort of the one place in government where people really are thinking well out into the future, that because of budget and other kinds of pressures and performance pressures that we perhaps are not looking as much into the future as we need to be, and that means in terms of investment in research and advanced technologies.

And so I wanted to actually follow up from Mr. Rohrabacher's question regarding intellectual property and intellectual property rights, because I think that, again, is a tough balance to strike. If you are trying to, you know, if you want to put out, you know, requests for really innovative research, then, you know, a scientist and researcher or an investigator wants to have some skin in the game, and part of that skin is potentially that, you know, great patent down the line.

And so I wonder if you could comment for me about how we can strike that balance of intellectual property rights and sharing so that we get, you know, the greatest bang for the buck and benefit as taxpayers but also incentivize some of our researchers to do that cutting-edge, risk-taking investigative work that we know should continue into the future.

And then I am also very interested to know on that question there are technologies and research going on in commercial spaceflight, in military space, and it seems that there are lots of walls and barriers in terms of sharing that innovative, intellectual property that is developed in each one of these spheres that I think gets in the way. You know, for example, if a technology is developed on the military space side, then we have, you know, some competitors around the world who are actually using some of those technologies and sharing them and commercializing them, but right here in this country those same technologies can't be shared on our civilian and commercial side. And that is a real downer when it comes to making investments in research.

And so I wonder if you can give me some thoughts about that and what we might think about in the Congress to try to mitigate that.

SHARING BETWEEN MILITARY AND COMMERCIAL DEVELOPERS

Mr. SCOLESE. Certainly. If I can take the last question first, the barriers for us to work with the—with our colleagues in other agencies in the government are not so great. We typically can do that quite well, and oftentimes when you are doing a research or a technology activity, it is not always known in the agencies which ones are there. So we have to have much stronger dialogues and that is something that I think we are all working on much more diligently now than we have in the past.

But even in the past we had, for instance, a technology, I forget the exact name because it keeps on changing, but a technology working group where our NASA chief engineer and before that our chief technologist would work with their DARPA colleagues and other colleagues from the Department of Defense or Department of Energy to go off and find areas of common interest.

ITAR

Further on that second part, the area where we really find that we hurt ourselves and we could really use help is with the ITAR, the International Traffic in and Arms Regulations, because that really limits our ability to take U.S. developed capabilities and bring those overseas where it could bring benefit to our companies. And even in the government, it is very difficult in government-to-government interactions for us to take technologies that we have and make them available so that it is a U.S.-developed technology and a U.S.-managed technology.

Instead, we develop it, someone sees it, and they will go off and invest their resources to go off and make the profit.

Ms. EDWARDS. I have an example of that right in my district.

Mr. SCOLESE. I am sure you do.

Ms. EDWARDS. And that is why I asked.

Mr. SCOLESE. Yes. Well, we both kind of worked at the same place at one point, so I figured that was probably the answer. On the earlier question about the intellectual property rights, it would probably be better if I took that one for the record and gave you all of the types of contracts that we have. Some have greater liberties for the inventor to go off and have property rights for those even if the government is funding it.

But it depends a lot on what that agreement says. So we have space act agreements and contracts and grants, and they are all a little bit different. So why don't I take for the record to get you a summary of what those are and what the intellectual property rights are associated with those various ones.

Ms. EDWARDS. I would appreciate that. Thank you.

Mr. SCOLESE. Okay.

Mr. GRIFFITH. The Chair is going to ask a few questions or make a few comments really. I think most of my questions have been answered.

This visual aid that was produced is absolutely impressive. I would say that you could also put a hospital room with a bed and a patient on this very page, and there would probably be greater than 18 improvements that have happened because of NASA, from the early diagnosis of breast cancer because of the innovations in the Hubble Telescope, to the miniaturizations of instruments that you have mentioned, to many, many things that have happened over the last 2 decades as a direct result of the innovations at NASA that we did not know were going to occur.

And that is one of the great benefits of research and development, one of the great benefits of science is that science has to prepare to discover, and then after it discovers, it discovers further what it did not know was there. I think Einstein said that research is something he does when he doesn't know what he is doing, and so I think we need to really emphasize the fact that research and development, whether it is the discovery of the Van Allen radiation fields, whether it is our continuing effort to improve materials so that we can further discover whether it be the neutron scattering and the elastic properties of radiation in material is absolutely critical to the advancement of science.

And NASA has been at the forefront of that, and I might take just one liberty to say that I think it is the absolute soul of America, both in its intellectual capabilities and equity and also in America's future, and I appreciate each and every one of you being here and coming from the Alabama Fifth District and Marshall Space Flight Center, you can see that I am a little bit prejudiced.

But I think Ranking Member Olson has another question.

Mr. OLSON. Thank you, Mr. Chairman. One more question for Dr. Colladay, and Dr. Colladay, you used to run NASA's Office of Aeronautics and Space Technology. NASA separated those research fields a few years ago with aeronautics placed in its own mission directorate and space technology placed into the exploration systems mission directorate.

Was that a good idea, or should the two be reunited into a single office? And as a follow up, would reuniting them strengthen technology developed by NASA, or is money the issue, not organization? And finally, would reuniting them suffice rather than creating a DARPA-like organization? I know it is a lot.

NASA ORGANIZATIONAL STRUCTURE

Mr. COLLADAY. Well, there were good and valid reasons for having the two combined when you get to the far-term, long-term base research, because when you are working computational fluid dynamics and advanced materials and the basic navigation and controls and sort of the basic disciplinary research and it is a long way from application, the people doing the research didn't always know they were spending an aeronautics R&D dollar or a space technology dollar. They were working on important and exciting engineering and science problems.

And so there was—there were certain number of advantages of having them together. They had to be defended separately. It gave enough critical mass that that person at the table that was—that I had spoke of as the champion defending advanced R&D had a big enough portfolio to be at the table.

But that is not the only way to do it. It—there are a lot of different governance models. Whatever governance model you look at, certain things have to be attended to, and I mention it in my remarks. One is when it is separate organizationally and put together as it was 20 years ago, aeronautics and space technology, you really have to put a lot of effort into making sure that what is being done is relevant.

You get criticism that, oh, they are just off playing in the sandbox. That is unfair a lot of times, but it points to the need and the organization that is responsible for advanced technology to make sure they are working with the user community, they are working with the ultimate developers to make sure that what they are working on has a transition path, it is relevant, and then a management approach or a governance model is in place to manage the transition of these great things that come out of the research that have to later be developed.

One thing in being a director of DARPA that I learned, it is, you know, we quit doing the research when we had proof of concept. If we proved that something was feasible, that was enough. We were off doing something else. A lot of work, a lot of hard work and money goes into taking those ideas and putting them to practice.

And so it is not enough to develop the technology, prove feasibility, create this environment where it is all right to take risks. You do all those things, and that is important, but there is—the ultimate user and the developer has to run with the early technology development along and parallel to manage the transition.

I don't know that on my watch in NASA that we always did a good enough job on those two points; relevancy, making sure that the ultimate user was involved, and that we managed the transition from what was code R into application. And the application sometimes wasn't with NASA at all. It was with industry.

Mr. OLSON. Thank you very much for that answer, Dr. Colladay. I see I have run out of my time. I yield back my time. Mr. Chairman.

Mr. GRIFFITH. Thank you, Ranking Member Olson. I am reminded before we close that the concept for high-speed CT Scanning was available to us 30 and 40 years ago. The coefficient of absorption and expansion I can remember working out problems with my slide rule and taking me a great deal of time, and it depended on our development outside of the concept of high-speed computing that allowed us to develop the CT Scan or even though we had the concept proven many, many decades before, so I think as pure R&D, pure science begins to develop. We serendipitously discover things over here that apply over here, and we can't always predict that.

Before we bring the hearing to a close, I want to thank each and every one of you for being here, and thank the witnesses and also our participants.

The record will remain open for 2 weeks for additional statements from the members and for answers to any follow-up questions the subcommittee may ask of the witnesses. The witnesses are excused, and the hearing is now adjourned.

[Whereupon, at 11:15 a.m., the Subcommittee was adjourned.]

Appendix:

ANSWERS TO POST-HEARING QUESTIONS

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Robert D. Braun, Co-Chair of the Committee To Review the Nasa Institute for Advanced Concepts, Aeronautics and Space Engineering Board, National Research Council

Questions submitted by Chairwoman Gabrielle Giffords

Disclosure: Since the October 22 hearing, I have had significant interaction with NASA personnel on this subject. However, the responses provided here to your questions reflect the deliberations of the National Academy Committee to Review the NASA Institute for Advanced Concepts and my own individual thoughts. I have indicated my personal views as such in the following responses.

Q1. In your prepared statement, you indicate that your panel felt that the former NIAC's complete focus on revolutionary concepts was too long term. As a result, your committee recommended that the new NIAC2 program should adopt a standard of "technically innovative" rather than "revolutionary", as was formerly used. By changing the standard to no longer stress revolutionary capabilities, would NASA run the risk of missing out on game-changing technologies?

A1. By definition, visionary advanced concepts will not be near-term. However, in our committee discussions, it was felt that NIAC's complete focus on revolutionary concepts (as directed in its NASA SOW) was too long-term, creating a cultural mismatch between the NIAC products and its mission-focused sponsors and causing infusion difficulties for the MIAC innovators. As such, the committee recommended that the key selection requirement for NIAC2 proposal opportunities be that the concept is scientifically and/or technically innovative and has the potential to provide major benefit to a future NASA mission of 10 years and beyond. While 10 years and beyond includes concepts that could be 40 years or farther in the future and revolutionary concepts are certainly scientifically and/or technically innovative, the committee felt that these modifications in focus would likely result in NIAC2 efforts with a higher probability of infusion into NASA's strategic planning process. In the committee's opinion, these changes would not constrain NASA from receiving and selecting revolutionary concepts (and their associated game-changing technologies) through future NIAC2 solicitations. Rather, such a change would also allow consideration of more near-term concepts, still a decade or more away from fruition, that have a higher likelihood of infusion into future NASA missions. The NIAC2 selection process would have to be designed to provide the appropriate balance between advanced concepts one decade or multiple decades into the future.

In addition, while NIAC's efforts were (and NIAC2's efforts should remain) on advanced concepts, other elements of a broadly focused NASA technology development program could specifically target proving the feasibility of game-changing technologies. Such demonstrations are likely to cost significantly more than a NIAC2 Phase I or Phase II concept study and require additional schedule. The proper suite of game-changing technology investments should result from integration of advanced systems analysis work (e.g., NIAC2 studies) overlaid upon a detailed set of technology roadmapping activities, developed by the knowledgeable technical community (both NASA and external technologists).

Q2. In your view, what would be an appropriate suite of NASA investments to address near-term, mid-term, and long-term technology needs?

A2. In my experience, there are three general classes of technology development programs: mission-focused (near-term), discipline-based (long-term), and capability-based (mid-range). NASA presently refers to these classes as mission-focused, early-stage and game-changing innovation, and crosscutting capabilities, respectively. While mid-term, capability-based technology investments are perhaps the most critical for a forward-looking Agency like NASA, within NASA today, this type of technology investment is minimal. In my view, this is not acceptable for an agency whose purpose includes demonstrating this nation's scientific and technological prowess, or one that is trying to inspire the next generation of engineers and scientists. It is from these capability-based technology developments (crosscutting capabilities) that NASA's next generation of missions will sprout. Today, a technology-poor NASA greatly hampers our aeronautics and space flight development programs. The lack of a crosscutting capability technology maturation program is perhaps the greatest deficiency in NASA's current approach to technology development.

I believe that NASA would be well served through a blend of technology development activities including the mission-focused technology presently performed in the NASA mission directorates (2–5 year maturation timeframe, moderate $ investment), capability-based technology (5–15 year maturation timeframe, large $ investment), and discipline-based technology (15–40 year maturation timeframe, modest $ investment). On top of the mission-focused technologies currently being pursued within the NASA mission directorates, a broadly-focused NASA technology development program should include a large number of small $ value "seed-fund" awards for long-term visionary concepts and early stage innovation, a smaller number of moderate $ value awards to mature a competitively selected set of game-changing technologies, and a few high $ value awards to mature selected crosscutting technologies to flight readiness status. I believe our nation would be well served by investing at least 10% of NASA's budget in support of the technologies required to dramatically advance entirely new aeronautics and space endeavors (in contrast to an investment of less than 3% today). This investment would include a small amount for advanced concepts so difficult to achieve that their chance of individual success within a decade is less than 10%, yet concepts so innovative that their success could serve as game-changers for this vital, national industry.

Q3. Your report indicates that the committee considered the model of each NASA Directorate having its own NIAC-like entity.

a. What are the pros and cons of having such "sub-NIAC" units within each mission directorate?

b. Why did your panel ultimately reject that model?

A3. The committee determined that two aspects that led to NIAC's termination were that (1) its focus was on far-term mission concepts that were not closely aligned with the lunar exploration architecture, and that (2) NIAC had limited success in infusing advanced concepts into NASA's strategic plans. Recognizing this relevance problem, the committee considered whether or not each NASA directorate should have its own NIAC-like entity. One potential advantage of such an arrangement is that each "sub-NIAC" could focus specifically on the advanced system and mission needs of its associated directorate, which likely would help each such organization to be more relevant to the directorate and would facilitate the infusion of results obtained. However, there are several disadvantages to such an arrangement, including (1) the management challenge of multiple mission directorate independent solicitations, (2) the need for proposers to be able to place their advanced concept within a specific mission directorate (whereas, many of the advanced concepts pursued by NIAC were at the intersection of multiple mission directorates), and (3) the integration of these mission-directorate advanced concepts with an eventual crosscutting capabilities demonstration program. In such a scenario, each mission directorate may also need to carry the funds and development programs to mature selected advanced concepts to flight readiness. As such, in the opinion of the committee, the efficiencies resulting from having a single organization solicit and manage advanced concepts for NASA as a whole were significantly compelling.

Q4. You said in your prepared statement that the lack of a NASA interface to receive the hand-off of promising projects was a persistent MIAC challenge. Consequently, your panel recommended improvement in how advanced concepts are infused into future systems.

a. Can you elaborate on what reestablishing an aeronautics and space systems technology development enterprise would entail from an organizational, programmatic, and cultural perspective?

b. What would the relationship between the proposed NIAC2 and this new enterprise?

c. If the enterprise is not established, could you still have a NIAC2 entity? Where would it reside organizationally?

A4. In the committee's opinion, the lack of a NASA interface to receive the hand-off of promising projects was a persistent NIAC challenge. To improve the manner in which advanced concepts are infused into its future systems and to build a culture that continuously strives to advance technology, the committee recommended that NASA consider reestablishing an aeronautics and space systems technology development enterprise. Such an organization would serve to preserve and increase the leadership role of the United States in aeronautical and space systems technology. Successfully reestablishing such an enterprise would have significant organizational, programmatic and cultural ramifications for NASA. As such, NASA's considerations for such an enterprise should include implications for the agency's strategic plan, effective organizational approaches, resource distributions, field center foci, and mission selection process. There are multiple organizational models that

NASA could choose to employ. To allow for successful, sustained implementation of a broadly focused NASA technology development program, such an enterprise should report to the Office of the Administrator, be outside the existing mission directorates, and be chartered to address NASA-wide mission and technology needs.

In my opinion, the cultural challenges facing such an enterprise, within NASA, are significant, as NASA has not been organized for the objective of technology development and innovation its development for some time. The reestablishment of creativity and innovation across the existing NASA workforce, and in the Agency's hiring practices, must be championed by this organization. Strong interactions with the academic community, national laboratories and industry research and development centers must be reestablished. Most importantly, this new NASA enterprise must be given permission to occasionally fail. A program focused on game-changing technology innovation should not be expected to succeed in each investment. However, on the whole, and over time, dramatic advances in aerospace technology that enable entirely new NASA missions and potentially, solutions to a wide variety of our society's grand technological challenges should be both expected and measured. Programmatically, this new enterprise must invest broadly across a wide range of innovations, across near-term, mid-range and long-term technology and advanced concepts efforts. This new enterprise must engage the top science and engineering talent in our nation, teaming NASA, industry and academic organizations, in coordination with other government agencies, independent of the workforce constraints at the NASA Centers. For long-term success, the budget stability of this enterprise must be assured.

If a broadly focused aeronautics and space systems technology development enterprise were farmed within NASA, the committee recommends that NIAC2 be an active element of its program, providing a broad range of advanced concept studies from both NASA and external innovators. The committee further believes that establishment of a NIAC2 activity is required whether or not a broadly focused aeronautics and space systems technology development enterprise is formed at NASA. If this new technology and innovation enterprise were not formed, the committee recommends that NIAC2 should report directly to the Office of the Administrator, be outside mission directorates, and be chartered to address NASA-wide mission and technology needs. However, the committee would like to point out that without establishment of a broadly focused aeronautics and space systems technology development enterprise, NIAC2 infusion objectives will likely continue to be a challenge.

Q5. Your panel's report stated that DARPA was the most frequently referenced model of success for advanced concept development.

a. What other models did your panel discuss?

b. In your opinion, in establishing a follow-on entity such as NIAC2, is it more important for NASA to have the right structure or the right priority?

A5. The committee spent a significant amount of time investigating and discussing DARPA and its model for advanced concept development and technology maturation. We also investigated and discussed previous and current NASA approaches including NASA's former Office of Aerospace Technology and former Office of Aeronautics and Space Technology, NASA roadmapping, Decadal Survey process and Vision mission studies conducted within or for the NASA Science Mission Directorate, and the Exploration Technology Development Program within the NASA Exploration Systems Mission Directorate. NASA Langley's Aerospace Systems Concepts and Analysis organization was discussed as were related approaches to concept development at the Jet Propulsion Laboratory and NASA Goddard Space Flight Center. Long-term research and innovation models at AFOSR, ARPA-E and NSF were also discussed as were advanced concept development approaches utilized by universities and industry.

In my opinion, in establishing a NIAC2, it is most important for NASA to give this advanced concepts organization sufficient priority, Agency-level visibility, freedom to establish the right technical content, and a stable funding level. The right program structure is an important asset for efficiency, but is not an absolute necessity.

Q6. Your panel's report indicates that potential awardees are concerned about investigator retention of rights data and associated intellectual property. How might NASA address their concern while ensuring the agency's investment is also protected?

A6. The committee heard from some MAC awardees, particularly small businesses that were uncomfortable with what they understood to be their rights to intellectual property developed under a NIAC award. While not uniform in these expressions, some NIAC awardees expressed uncertainties about the status of intellectual property for proposals submitted to NIAC and the status of intellectual property rights for work developed under NIAC support. As such, the committee recommended that NIAC2 develop and document a policy allowing awardees rights to data and associated intellectual property to address these issues before soliciting any proposals. As an organization with a focus on the development of new concepts and technologies, NIAC was and NIAC2 would be in an ideal position to foster an innovative program of intellectual property management and train its innovators in how to manage intellectual property and their rights in compliance with the law and government policy. The committee also recommended that NASA, through NIAC2, allow awardees to retain rights to data and associated intellectual property developed under NIAC2 awards. The committee believes that in these matters the financial risk to the government is small, while the potential commercial benefit to our nation is large.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Raymond S. Colladay, Vice Chair of the Committee on Rationale and Goals of the U.S. Civil Space Program, Aeronautics and Space Engineering Board, National Research Council

Questions submitted by Chairwoman Gabrielle Giffords

Q1. Your committee's report states that "Space activities provide economic opportunities, stimulate innovation and support services that prove the quality of life. US. economic competitiveness is directly affected by our ability to perform in this sector and the many sectors enabled and supported by space activities. "The report also says that "The United States is now living on the innovation funded in the past".

Q1a. Is your report suggesting that NASA is no longer in a position of enabling significant technological innovation?

A1,1a. Nothing that a commitment to fund advanced technology research and development would not solve. NASA has the people with the skills and a clear charter in the Space Act to conduct technology research and development that can lead to the kind of innovation envisioned in the report. It takes a commitment to invest the resources to sustain such research over the long haul—something that has been missing lately.

Q1b. In today's environment where near term challenges command our attention and resources, how do we convince the rest of the Congress that the "seed corn" of technology development is a critical top priority?

A1,1b. The best rationale for investment in technology research and development is based on making the case for the importance of maintaining our technological competitiveness. NASA's mission and US prestige that comes with the space program rests on technological excellence—excellence which cannot be sustained without up-front investment in technology. Unfortunately, the case is easier to make now, because the consequences of not making the necessary investments are evident today in cost overruns; less capable missions, fewer good technical options to meet requirements, and a lack of true game-changing opportunities.

Q2. Your report discusses the broad customer base that would benefit from the multi-use technologies including NASA, NOAA, industry, and military space programs. Some multi-use technologies might be of more interest and pertinence to certain users.

Q2a. How would the selection process ensure balance among the users?

A2,2a. If NASA is truly conducting and sponsoring technology research and development at the cutting edge boundaries of science and engineering for space applications, balance among ultimate users of the resulting technology is best addressed later in the process during transition to application. DOD and/or industry will adapt whatever technological breakthroughs appear to be in their best interests and they should pay for it when it reaches that stage. NASA can be a catalyst for innovation by investing in very advanced concepts where balance is based on competition of the best ideas from the most talented people with the greatest potential pay-off.

Q2b. How would a DARPA-like entity balance technologies that address long-term user needs and in supporting highly visionary technology concepts for which uses are not yet known or defined?

A2,2b. If a DARPA-like entity is created to address technology research and development, then its mission should be weighted primarily towards the highly visionary technology concepts. That is the part of the R&D spectrum that is most in need of emphasis in NASA right now.

Q2c. Who should provide the funding for such multi-use technology efforts?

A2,2c. NASA should. It is explicit in their charter and the ultimate user is, as you say, not yet defined. It will always require orders-of-magnitude more money to transition products of technology research and development to application, which is when others (e.g. DOD or industry) should expect to carry the funding load.

Q3. Your report notes that one of the goals of the civil space program should be "To provide technological, economic, and societal benefits that contribute to the nation's most pressing problems."

Q3a. How would the DARPA-like entity discussed in your report address broader, national needs?

A3,3a. NASA should stay closely bound to their space and aeronautics mission. It is a very stressing mission that pushes the boundaries of engineering disciplines that benefit broader national needs when considering potential applications beyond aviation and space: As such, space and aeronautics is an engine for technological innovation, but the ultimate application of the technology may be in fields far from aerospace. DARPA has been most effective when it stays focused on its military mission, but the technology breakthroughs it has enabled have led to advances far beyond just the military. Clearly, however, NASA should partner and collaborate with their research counterparts in DOD, industry, and other government agencies and departments in a culture of cooperation in technology R&D.

Q3b. How would technology areas be prioritized, especially if the goal of the DARPA-like organization is to "support preeminent civil, national security. . ., and commercial space programs" as your committee recommends?

A3,3b. Priorities should be established through a competition of ideas—the best research, by the best people, with the best ideas. There will always be limited funding, so the competition should be intense.

Q4. DARPA is often characterized as having a risk -taking culture, one that conducts long-term, high-risk, high payoff research, is tolerant of failure, and is open to learning. Is it realistic to expect such risk taking to succeed in NASA in light of fiscal constraints that emphasize near term mission success?

A4. You raise one the strongest arguments in my opinion to separate an organization within NASA to undertake this very advanced, game-changing technology research and development. As a whole, NASA must and should be risk averse, particularly with human space flight. Mission success is paramount in human space flight and also in many of the grand space science mission. if the charter for innovative technology research and development is dispersed throughout the agency in all the mission areas, it can be very confusing to the culture and the workforce to say safety and mission success is paramount and at the same time parse the message that there needs to be a high tolerance for risk and failure is acceptable if reaching for an aggressive goal. it seems to me that the leadership can encourage a DARPA-like organization with NASA to take that high-risk path if it is understood that rest of the organization, particularly human space flight, stays focused on safety and mission success where failure cannot be an option. Advanced technology research and development is precisely where risk should be taken and in so doing, the risk is wrung out before the technology is applied to an operational mission.

Q5. You note in your prepared statement that DARPA-like organization adapted for NASA should be "relieved of NASA institutional requirements". Could you elaborate on what requirements you would target?

A5. If technology R&D is to promote a competition of the best ideas by the best people wherever they reside—NASA Centers, universities, other government labs, or industry—then resources should not be preferred to the particular NASA Centers in need of institutional support such as building a centers core competency. It may happen that it accomplishes exactly that, but it should be because the people or the ideas from that center are best in class.

Q6. Regarding your panel's recommendation that NASA revitalize its advanced technology development program by establishing a DARPA-like organization within NASA, can you clarify what would happen to the advanced aeronautics research currently conducted in ARMD under your approach?

A6. There are many organizational models and most have been tried in one form or another. Aeronautics could be part of it, like it once was, and there are arguments both for and against. Either way, aeronautics in NASA is a vitally important mission area and needs to be supported either as part of a DARPA-like organization whose charter is broadly "aerospace", or separate.

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