ENSURING THE SAFETY OF HUMAN SPACEFLIGHT

HEARING

BEFORE THE

SUBCOMMITTEE ON SPACE AND AERONAUTICS

COMMITTEE ON SCIENCE AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

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December 2, 2009

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ENSURING THE SAFETY OF HUMAN SPACEFLIGHT

WEDNESDAY, DECEMBER 2, 2009

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

The Subcommittee met, pursuant to call, at 10:00 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Gabrielle Giffords [Chairwoman of the Subcommittee] presiding.

HEARING CHARTER

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

Ensuring the Safety of Human Space Flight

DECEMBER 2, 2009
10 A.M.–NOON
2318 RAYBURN HOUSE OFFICE BUILDING

I. Purpose

On December 2, 2009 the Subcommittee on Space and Aeronautics will hold a hearing focused on issues related to ensuring the safety of future human space flight in government and non-government space transportation systems. The hearing will examine (1) the steps needed to establish confidence in a space transportation system's ability to transport U.S. and partner astronauts to low Earth orbit and return them to Earth in a safe manner, (2) the issues associated with implementing safety standards and establishing processes for certifying that a space transportation vehicle is safe for human transport, and (3) the roles that training and experience play in enhancing the safety of human space missions.

II. Scheduled Witnesses:

Mr. Bryan D. O'Connor
Chief of Safety and Mission Assurance
National Aeronautics and Space Administration

Mr. Jeff Hanley
Program Manager
Constellation Program
Exploration Systems Mission Directorate
National Aeronautics and Space Administration

Mr. John C. Marshall
Council Member
Aerospace Safety Advisory Panel
National Aeronautics and Space Administration

Mr. Bretton Alexander
President
Commercial Spaceflight Federation

Dr. Joseph R. Fragola
Vice President
Valador, Inc.

Lt. Gen. Thomas P. Stafford, USAF (ret.)

III. Overview

The Review of U.S. Human Space Flight Plans Committee, also known as the Augustine committee, recently issued its final report. The committee was tasked to "*conduct an independent review of ongoing U.S. human space flight plans and programs, as well as alternatives, to ensure the Nation is pursuing the best trajectory for the future of human space flight—one that is safe, innovative, affordable, and sustainable. The review committee should aim to identify and characterize a range of options that spans the reasonable possibilities for continuation of U.S. human space flight activities beyond retirement of the Space Shuttle.*"

As directed, the committee's final report offered a number of options to the president for the conduct of future space exploration, ranging from continuing with the Constellation Program of Record (with slight modifications) to pursuing a "flexible path" with alternative launch vehicles, including modified Evolved Expendable Launch Vehicles (EELV) currently used primarily by the Department of Defense to transport military payloads. Several of the committee's options included the use of as-yet-to-be-developed commercial services to provide future crew transportation to and from the International Space Station (ISS) following retirement of the Space Shuttle. While the committee stated that it recognized both the risks and opportunities presented by commercial crew services, it believed such services could be available by 2016. Specifically, the report stated:

> *"The United States needs a way to launch astronauts to low-Earth orbit, but it does not necessarily have to be provided by the government. As we move from the complex, reusable Shuttle back to a simpler, smaller capsule, it is an appropriate time to consider turning this transport service over to the commercial sector. This approach is not without technical and programmatic risks, but it creates the possibility of lower operating costs for the system and potentially accelerates the availability of U.S. access to low-Earth orbit by about a year, to 2016. The Committee suggests establishing a new competition for this service, in which both large and small companies could participate."*

Using commercial providers for space transportation is not a new idea. Congress has encouraged NASA to use commercial transportation services when appropriate as part of its space exploration strategy. Support for the commercial space industry was affirmed in P.L. 110–422, the National *Aeronautics and Space Administration Authorization Act of 2008*. Along with that support however was a requirement for commercial services' prior conformance with NASA's safety requirements. Specifically, regarding crew transportation, the Act stated in Sec. 902 that the National Aeronautics and Space Administration (NASA) shall:

> *"make use of United States commercially provided International Space Station crew transfer and crew rescue services to the maximum extent practicable, if those commercial services have demonstrated the capability to meet NASA-specified ascent, entry, and International Space Station proximity operations safety requirements."*

Those NASA safety requirements are primarily embodied in NASA Procedural Requirements (NPR) document NPR 8705.2B, "*Human-Rating Requirements for Space Systems*" as well as in the ISS Visiting Vehicle requirements that govern proximity operations around the ISS. While the NPR requirements apply to the development and operation of crewed space systems developed by NASA and used to conduct NASA human spaceflight missions, the NPR also states that it "*may apply to other crewed space systems when documented in separate requirements or agreements*".

Progress has been made in the past few years by commercial entities in designing and developing cargo launch capabilities which have the potential to access the ISS. However, they are not scheduled to demonstrate the capability to transport cargo to the ISS as part of NASA's Commercial Orbital Transportation Services (COTS) Demonstration project until the second quarter of Fiscal Year 2010, at the earliest. The transporting of NASA astronauts to low Earth orbit and ensuring their safe reentry to Earth is considered to be significantly more challenging than transporting cargo to the ISS.

That is the crux of the issue. Establishing and enforcing safety standards for the transport of crew on commercially provided orbital crew transportation services is in many ways uncharted territory. Furthermore, a process has yet to be advanced by the government on how the "airworthiness" of commercial space flight vehicles used to transport government passengers will be "certified". While the Augustine committee's report projected that commercial crew transportation services could be available in 2016, it does not appear that the committee's projection accounts for all of the milestones that must be met prior to the point at which NASA would be able to use such services to fly its astronauts to the ISS. Notionally, these include: prior Congressional authorization and appropriation of funds for such an activity, which could not occur before enactment of the FY 2011 appropriation for NASA at the earliest; agreement on human-rating and other safety standards and means for verifying compliance, development and implementation of new safety processes, testing and verification procedures to ensure safety, and potentially a new regulatory regime for certification; development of a COTS-like demonstration program open to multiple participants and competition/award of Space Act Agreements for the demonstration program; completion of the development/demonstration program, which would need to include a TBD number of demonstration flights, including tests of launch escape systems, etc.; subsequent preparation of an RFP for commercial crew transportation/ISS crew rescue services; contract competition, negotiation and award of contract(s), and potential protest(s) by losing bidder(s) [which unfortunately has become a more frequent occurrence in recent Department of Defense (DoD)/NASA contract competitions]; manufacturing of the operational flight vehicle systems [some of which could potentially be initiated during the development/demonstration phase, assuming the companies would be able to fund those tasks with private capital]; TBD number of "certification" flights of the production vehicle system prior to NASA agreement to put its astronauts on board; and finally, commencement of initial operations to and from the ISS.

Any mismatch between the timetable asserted in the Augustine committee's report and the actual time required to bring commercially provided crew transportation services to operational status is relevant because it highlights a potential inability to meet even a fraction of NASA's crew transfer needs for the ISS prior to the end of even an extended ISS operations period [i.e., an ISS extension to 2020], which in turn calls into question the ability of would-be commercial providers to identify a credible government market when seeking private capital commitments. In the absence of a government commitment to pay for services whether or not they are available when needed, would-be commercial providers could face pressures to cut costs [or cease to compete], and the government would thus have to be vigilant to ensure that safety-related processes and practices were not compromised as a result.

Regardless of the approach to NASA's human space flight and exploration program that is recommended to Congress by the president, commercial space providers may well play an expanding role in transporting cargo to low Earth orbit (LEO) and eventually beyond LEO, and potentially transporting crew to and from LEO in the future. Consequently, it is prudent to initiate a detailed examination of the steps needed to establish confidence in commercial space transportation systems' capabilities to transport U.S. and partner astronauts to low Earth orbit and return them to Earth safely.

At the hearing, witnesses will provide a historical perspective on the establishment of safety requirements in NASA human space flight systems; NASA's efforts to develop human safety standards and requirements; the incorporation of crew safety requirements in the design of NASA's Constellation Program; and the commercial space transportation companies' expectations of how NASA's safety standards and requirements would be applied to commercial spacecraft as well as the level of governmental insight and oversight over their development activities and operations that they would consider appropriate.

IV. Issues

The hearing will focus on the following questions and issues:

- *What are the most important safety-related issues that need to be addressed in either a government or non-government space transportation system?*
- *What would be the safety implications of terminating the government crew transportation system currently under development in favor of relying on as-yet-to-be-developed commercially provided crew transportation services? What would the government be able to do, if anything, to ensure that no reduction in planned safety levels occurred as a result?*
- *What expectations should Congress have regarding the safety standards commercial providers should meet if their proposed crew transportation and ISS crew rescue services were to be chosen by NASA to carry its astronauts to low Earth orbit? What would be required to verify compliance with those standards?*
- *If a policy decision were made to require NASA to rely solely on commercial crew transfer services, which would have to meet NASA's safety requirements to be considered for use by NASA astronauts, what impact would that have on the ability of emerging space companies to pursue innovation and design improvements made possible [as the industry has argued] by the accumulation of flight experience gained from commencing revenue operations unconstrained by a prior safety certification regime? Would it be in the interest of the emerging commercial orbital crew transportation industry to have to be reliant on the government as its primary/sole customer at this stage in its development?*
- *What lessons learned from the evolution of NASA's human space flight systems should be reflected in the design and operation of future crewed space transportation systems, whether government or non-government?*
- *What role does NASA's Office of Safety and Mission Assurance play in ensuring the safety of human space flight at NASA? What initiatives does the office have underway to enhance the safety of human space flight at NASA?*
- *What is being done to communicate NASA's safety and human-rating requirements to potential commercial crew space transportation and ISS crew rescue services providers?*

- *How and to what extent did safety considerations, especially with respect to launch, inform the choices made in NASA's Exploration Systems Architecture Study (ESAS)?*
- *How has the Constellation Program incorporated safety and applicable human-rating requirements, as well as Astronaut Office input on launch/entry systems safety, into the program's design, development, and testing activities?*
- *What has NASA learned so far in executing the Constellation Program that can assist in developing a better understanding of the impact of design features, development and testing and manufacturing processes, and operations procedures on the safety of crewed space transportation system alternatives?*
- *What are the expectations of potential commercial crew transportation services providers as to how safety standards and processes will be determined if the government decided to use commercial services for the transport of NASA astronauts to and from low Earth orbit and the ISS?*
- *What do potential commercial crew transportation services providers consider to be an acceptable safety standard to which potential commercial providers must conform if their space transportation systems were to be chosen by NASA to carry its astronauts to low Earth orbit and the ISS? Would the same safety standard be used for non-NASA commercial human transportation missions?*
- *What do potential commercial crew transportation services providers consider to be an acceptable level of insight and oversight over their development, test, and manufacturing process, their vehicles, and operations if their services are used to transport NASA astronauts to and from low Earth orbit and provide ISS crew rescue services?*
- *What do potential commercial crew transportation services providers consider to be an acceptable certification regime that potential commercial services providers must comply with to address the government's regulatory responsibilities over the safety and "air worthiness" of commercial crew transportation vehicles prior to their approval for use in revenue-generating flight operations, whether for government or non-government customers?*
- *What training and familiarization with non-NASA crewed spacecraft and launch vehicles would astronauts flying on such non-NASA spacecraft and launch vehicles need in order to deal with off-nominal conditions, contingency operations and emergencies?*

V. Background

Relevant Legislation and Hearing on Safety Issues Associated with Commercial Space Launches

NASA Authorization Act of 2005

P.L. 109–155, the *National Aeronautics and Space Administration Authorization Act of 2005*, directed that an independent presidential commission be established to investigate incidents resulting in the loss of a U.S. space vehicle used pursuant to a contract with the Federal government or loss of a crew member or passenger in such a vehicle. The Act made clear that Congress believed that an accident involving astronauts riding on a commercial vehicle would be treated as at least as serious a matter as one involving a government vehicle. Specifically, the Act specified:

> *"(a) ESTABLISHMENT.—The President shall establish an independent, nonpartisan Commission within the executive branch to investigate any incident that results in the loss of—*
>
> *(1) a Space Shuttle;*
>
> *(2) the International Space Station or its operational viability;*
>
> *(3) any other United States space vehicle carrying humans that is owned by the Federal Government or that is being used pursuant to a contract with the Federal Government; or*
>
> *(4) a crew member or passenger of any space vehicle described in this subsection.*
>
> *(b) DEADLINE FOR ESTABLISHMENT.—The President shall establish a Commission within 7 days after an incident specified in subsection (a)."*

The independent commission would be tasked, to the extent possible, to investigate the incident; determine the cause of the incident; identify all contributing factors to the cause of the incident; make recommendations for corrective actions; providing any additional findings or recommendations deemed by the Commission to be important; and prepare a report to Congress, the president, and the public.

NASA Authorization Act of 2008

The Congress affirmed its support for the commercial space industry in P.L. 110–422, the *National Aeronautics and Space Administration Authorization Act of 2008*. The Act states in its findings that

> *"Commercial activities have substantially contributed to the strength of both the United States space program and the national economy, and the development of a healthy and robust United States commercial space sector should continue to be encouraged."*

With regards to the potential use of commercially-provided ISS crew transfer and crew rescue services, the Act states that NASA may make use of commercial services if those commercial services have demonstrated the capability to meet NASA's safety requirements. Specifically, the Act states:

> *"(a) IN GENERAL.—In order to stimulate commercial use of space, help maximize the utility and productivity of the International Space Station, and enable a commercial means of providing crew transfer and crew rescue services for the International Space Station, NASA shall—*
>
> *(1) make use of United States commercially provided International Space Station crew transfer and crew rescue services to the maximum extent practicable, if those commercial services have demonstrated the capability to meet NASA-specified ascent, entry, and International Space Station proximity operations safety requirements;*
>
> *(2) limit, to the maximum extent practicable, the use of the Crew Exploration Vehicle to missions carrying astronauts beyond low Earth orbit once commercial crew transfer and crew rescue services that meet safety requirements become operational;*
>
> *(3) facilitate, to the maximum extent practicable, the transfer of NASA-developed technologies to potential United States commercial crew transfer and rescue service providers, consistent with United States law; and*
>
> *(4) issue a notice of intent, not later than 180 days after the date of enactment of this Act, to enter into a funded, competitively awarded Space Act Agreement with 2 or more commercial entities for a Phase 1 Commercial Orbital Transportation Services crewed vehicle demonstration program."*

However, with respect to subsection (4) above, the 2008 Act also made clear in Sec. 902(b) that:

> *"(b) CONGRESSIONAL INTENT.—It is the intent of Congress that funding for the program described in subsection (a)(4) shall not come at the expense of full funding of the amounts authorized under section 101(3)(A), and for future fiscal years, for Orion Crew Exploration Vehicle development, Ares I Crew Launch Vehicle development, or International Space Station cargo delivery."*

Government Indemnification for Commercial Space Launch Operations

In 1988, Congress amended the *Commercial Space Launch Act of 1984* to indemnify the commercial space launch industry against successful claims by third parties. Specifically, the United States agreed, subject to appropriation of funds, to pay third party claims against licensees in amounts up to $1.5 billion [in 1989 dollars] above the amount of insurance that a licensee carries. The Act's definition of "third party" excludes all government employees, private employees, and contractors involved directly with the launch of a vehicle.

The Act requires that private launch companies purchase sufficient liability insurance. This amount is determined by the Federal Aviation Administration (FAA) on a case-by-case basis depending on its calculation of the "maximum probable loss" from claims by a third party. This amount is capped at $500 million for coverage against suits by private entities.

Since the majority of commercial launch activity occurs at federal launch ranges, the Act also requires any insurance policy a company obtains to also protect the federal government, its agencies, personnel, contractors, and subcontractors. The liability insurance section of the Act requires reciprocal waivers of claims between the licensee and its contractors, subcontractors, and customers. In effect, the licensee and any other organization assisting in the actual launch are prevented from seeking damages from one another. The indemnification and liability regime was first established by Congress as part of the Commercial Space Launch Act Amendments of 1988 and has been extended four times since its original enactment. On October 20, 2009, the U.S. House of Representatives passed H.R. 3819, a bill to extend the commercial space transportation indemnification and liability regime, by a voice vote. The liability risk-sharing regime extension is set to expire at the end of the year; H.R. 3819 would extend it for three more years. Congress has not yet explicitly addressed the issues of indemnification and liability for future commercially provided orbital human space flight services.

Commercial Space Launch Amendments Act of 2004

The Commercial Space Launch Amendments Act of 2004 put an initial regulatory framework in place for commercial human space flight. The intent of the law was to support the development of this private sector effort while also protecting the safety of uninvolved public on the ground. The law established an "informed consent" regime for carrying space flight crew and participants (passengers). The Act also created a new experimental launch permit for test and development of reusable suborbital launch vehicles. The 2004 law called for FAA to "*encourage, facilitate, and promote the continuous improvement of the safety of launch vehicles designed to carry humans*." To allow the industry to grow and innovate, the Act stated that "*Beginning 8 years after the date of enactment of the Commercial Space Launch Amendments Act of 2004, the Secretary may propose regulations*" pertaining to crew and passengers, further adding that "*Any such regulations shall take into consideration the evolving standards of safety in the commercial space flight industry*." The eight year period [which ends in 2012] reflected the view that by then, the commercial human space flight industry would be "*less experimental*."

As part of the "informed consent" regime, FAA regulations require an operator to inform in writing any individual serving as crew that the United States Government has not certified the launch vehicle and any reentry vehicle as safe for carrying flight crew or space flight participants. Similarly, the operator must inform each space flight participant in writing about the risks of the launch and reentry, including the safety record of the launch or reentry vehicle type. The "informed consent" rules became effective in December 2006.

FAA's subsequent rules call for launch vehicle operators to provide certain safety-related information and identify what an operator must do to conduct a licensed launch with a human on board. The protocols also include training and general security requirements for space flight participants. As part of the new measures, launch providers must also establish requirements for crew notification, medical qualifications, and training, as well as requirements governing environmental control and life-support systems. An operator must also verify the integrated performance of a vehicle's hardware and any software in an operational flight environment before carrying a space flight passenger. However, in issuing operator licenses, FAA does not certify the launch vehicle as safe as the agency customarily does with aircraft. In the latter case, the agency's Office of Aviation Safety provides initial certification of aircraft and periodically inspects an aircraft and certifies it as safe to fly. With regards to spacecraft, FAA can also issue experimental permits for launches of reusable vehicles conducted for research and development activities related to suborbital flight, for demonstrations of compliance with licensing requirements, or for crew training before obtaining a license.

2003 Joint Hearing on Commercial Human Space Flight

The Subcommittee and the Senate's Subcommittee on Science, Technology, and Space of the Committee on Commerce, Science and Transportation held a hearing entitled *Commercial Human Space Flight* in July 2003. Among the issues discussed at the joint hearing were when revenue launches would begin to happen, "what is safe enough", and whether the government should certify the safety of commercial vehicles prior to the commencement of passenger-carrying operations.

At the 2003 hearing, Senator Sam Brownback asked the witnesses when they could take their first commercial paying human customer into space. Mr. Jeff Greason, President of XCOR Aerospace said:

> *"That depends, in part, on factors that are not entirely in my control, like how fast we lock up some of the remaining investment. But if the investment is in hand, not sooner than about three years, because we have an extensive test program we have to go through."*

In response to Senator Brownback's question, Mr. Elon Musk, the CEO of Space Exploration Technologies, said:

> *"Well, the task that SpaceX has set for itself is probably an order of magnitude greater than sub-orbital flight. We've really aimed at orbital flight, really essentially the job that the Space Shuttle does. That's a longer road. But I think it's conceivable we could get something done in the 2006 time frame, as well."*

With regards to safety, then-Subcommittee Ranking Member Bart Gordon asked Mr. Greason "*What is safe enough, and who should verify that*?" Mr. Greason replied:

"I mean, it's safe enough when the customers start to show up, and you go through a process of demonstrating the vehicle over and over and over again. Now, we have our own internal business targets about how safe we have to know it is before we can base a business on it. But it's important to realize that long before we get to the point where we know it's safe enough that our expensive asset won't crash and be lost to revenue service, something we have to do for our own business, long before that point, we will have demonstrated safety far superior to what people think of as space flight safety as being right now. I mean, the test program, alone is probably going to be 50 flights."

In a response to a question for the record posed by then-Subcommittee Chairman Dana Rohrabacher to Mr. Dennis A. Tito, CEO of Wilshire Associates, Inc, on what features of current aircraft standards and space launch safety standards should be applied to commercial human space flight, Mr. Tito provided the following response:

"As I stated in my testimony, commercial aviation is a mature and well-established industry. Aircraft safety standards reflect 100 years of powered flight experience, and are part of a 75+ year history of federal regulation increasingly focused on protecting the safety of airline passengers as well as uninvolved third parties. The commercial space launch industry is a somewhat less mature industry, with just over two decades of commercial experience. This industry's heritage, however, is based on over a half-century of military and civilian development and testing of ballistic missiles and their descendant launch vehicles. Missiles and most current launch vehicles have significant destructive potential and, because they are expendable, cannot be flight tested, fixed, and re-tested in the way aircraft or other reusable systems can. Launch safety standards have therefore focused on detailed oversight, complex system redundancy and flight termination (self-destruct) capabilities. Neither of these two operational safety paradigms is appropriate for commercial human space flight. There may be some similarities between aircraft and sub-orbital reusable launch vehicles, and others between RLVs [Reusable Launch Vehicles] *and expendable rockets. However, I predict that these new space planes will in fact merit their own operational safety approaches. At this point, we need to develop and fly some vehicles so we can learn what to do and what not to do. That, after all, is the beauty of the competitive marketplace: better ideas are rewarded while less-good approaches suffer until they are improved or die off."*

Responding to a similar question for the record by Mr. Gordon on whether the government should certify the safety of his vehicles prior to commencement of passenger-carrying operations, Mr. Greason replied:

"The government should absolutely not certify the safety of our vehicles prior to the commencement of commercial, passenger-carrying operations. Today, we have a gap of one-million-to-one between the safety of space flight (roughly 40 fatalities per thousand emplanements for U.S. space missions) and aircraft (roughly 25 fatalities per billion emplanements for U.S. scheduled air carriers). When aviation started, its accident rate was as bad or worse than today's space transportation technology. In the early days, carrying passengers for "barnstorming" was one of the few sources of revenue in the aircraft industry. Today, risk tolerance is lower than in the 1920s. We believe we can and must do better. But if commercial RLV operators are ten times safer than government space flight efforts (which may be achievable), that is still 100,000 times less safe than aircraft. We are clearly too early for any kind of certification regime as that practiced in commercial aviation.

Early generation RLVs should be allowed to fly as long as the uninvolved general public are kept reasonably safe. The key is a system which investigates failures and shares the methods used successfully. The best and fastest path to safety is establishing a regulatory culture of continuous improvement based on experience; and the more flights we get, the faster we will gain that experience. Attempts to shortcut this process by establishing standards based on guesses or predictions about future technologies will stifle innovation, fix in place present practices, and slow the pace of safety improvement. This might not be so bad if the current safety record of space transportation were something to preserve. But it is not; it is something to change for the better."

"The current safety situation will change when operational track records are established. It is very likely that there will be dramatic differences in safety between vehicle types. When that happens, AST, industry, and the NTSB need to

collaborate on raising the bar, perhaps by establishing minimum safety records, perhaps by design standards, or a mix of both. As this evolves, it will be important to avoid applying these new regulations to vehicle test flights. Research and development test flights should continue with the sole burden of protecting the safety of the general uninvolved public. In this way we can hope that people will look back on the first century of private space flight and see the same dramatic improvement in safety which has been demonstrated by aircraft."

In addition to illuminating the discrepancy between the schedule predictions of the emerging commercial providers and their actual performance to date, the testimony cited above raises the policy issue of the potential impact of a decision to require NASA to rely on commercially provided crew transportation services, which would have to meet NASA's safety requirements prior to NASA having its astronauts utilize those services. Given that the emerging commercial providers appear to believe strongly in an evolutionary approach to design and safety innovation to be achieved through flight experience gained from revenue flights undertaken without any prior safety certification regime, premature reliance on the government as the dominant/only customer would call into question the ability of the emerging commercial providers to sustain the approach to innovation that they appear to believe is essential to their long-term success.

NASA's Incorporation of Safety Measures into Its Human Space Flight Programs

Several key safety initiatives were undertaken by NASA following the experience gained from flight missions:

- In January 1986, the Space Shuttle *Challenger* and its crew were lost 73 seconds after launch because of the failure of a seal (an O-ring) between two segments of a Solid Rocket Booster. In response to the findings of the Rogers Commission that investigated the *Challenger* accident, NASA established what is now known as the Office of Safety and Mission Assurance (OSMA) at Headquarters to independently monitor safety and ensure communication and accountability agency-wide. The Office monitors "out of family" anomalies and establishes agency-wide Safety and Mission Assurance policy and guidance such as human-rating requirements to which NASA program managers must adhere. OSMA also reviews the Space Shuttle Program's Flight Readiness Process and signs the Certificate of Flight Readiness.
- In February 2003, Shuttle *Columbia* disintegrated as it returned to Earth. In the ensuing investigation by the *Columbia* Accident Investigation Board (CAIB), the CAIB found that *Columbia* broke apart from aerodynamic forces after the left wing was deformed from the heat of gases that entered the wing through a hole caused during launch by a piece of foam insulation that detached from the External Tank. The CAIB found that the tragedy was caused by technical and organizational failures and provided 29 recommendations.

  Then-NASA Administrator Sean O'Keefe requested that Lt. Gen. Thomas Stafford, U.S. Air Force (Ret.) assign his Task Force on International Space Station Operational Readiness to undertake an assessment of NASA's plans to return the Space Shuttle to flight. At that time, the Stafford Task Force was a standing body chartered by the NASA Advisory Council, an independent advisory group to the NASA Administrator. Lt. Gen. Stafford activated a sub-organization with Col. Richard O. Covey, U.S. Air Force (Ret.) leading the day-to-day effort of conducting an independent assessment of the 15 CAIB "return-to-flight" recommendations. As a result, the Return to Flight Task Group was chartered in July 2003. Over the next two years, using expertise from academia, aerospace industry, the federal government, and the military, the task group, with Lt. Gen. Stafford and Col. Covey as co-chairs, assessed the actions taken by NASA to implement the 15 CAIB return-to-flight recommendations plus one additional item the Space Shuttle Program assigned to itself as a "raising the bar" action. The task group conducted fact-finding activities, reviewed documentation, held public meetings, reported the status of its assessments to NASA's Space Flight Leadership Council, and released three interim reports. The task group issued its final report (dated July 2005) on August 17, 2005.

  Lt. Gen. Stafford will be a witness at the hearing and can provide insights into safety challenges associated with human space flight.
- Among the CAIB's recommendations was one for NASA to establish an independent Technical Engineering Authority responsible for technical requirements and all waivers to them. In response, NASA created the NASA Engineering and Safety Center's (NESC) whose mission is to perform value-added

independent testing, analysis, and assessments of NASA's high-risk projects to ensure safety and mission success.

According to NASA, rather than relieving NASA program managers of their responsibility for safety, the NESC complements the programs by providing an independent technical review. Additionally, NASA states that the NESC provides a centralized location for the management of independent engineering assessment by expert personnel and state of the art tools and methods for the purpose of assuring safety. The NESC Management Office is located at NASA Langley Research Center in Hampton Virginia, but the NESC has technical resources at all 10 NASA Centers and Headquarters, as well as partnerships with academia, industry and other Government organizations. These technical resources are pooled to perform NESC activities and services. Operationally, the NESC falls under the responsibility of NASA's Office of Safety and Mission Assurance.

- NASA said that it recognized the importance of capturing the lessons learned from the loss of *Columbia* and her crew to benefit future human exploration, particularly future crewed vehicle system design. Consequently, the Space Shuttle Program commissioned the Spacecraft Crew Survival Integrated Investigation Team (SCSIIT) to perform a comprehensive analysis of the accident, focusing on factors and events affecting crew survival; and to develop recommendations for improving crew survival for all future human space flight vehicles. The Team's final report was released in December 2008, although findings were shared within NASA during the 3-year effort. Some illustrative recommendations with regards to future space craft design were as follows:
    - *"Future spacecraft seats and suits should be integrated to ensure proper restraint of the crew in offnominal situations while not affecting operational performance. Future crewed spacecraft vehicle design should account for vehicle loss of control to maximize the probability of crew survival."*
    - *"Future vehicle design should incorporate an analysis for loss of control/breakup to optimize for the most graceful degradation of vehicle systems and structure to enhance chances for crew survival. Operational procedures can then integrate the most likely scenarios into survival strategies."*
    - *"Future spacecraft crew survival systems should not rely on manual activation to protect the crew."*

The Constellation Program's design is in conformance with the Team's findings. For example, with regards to the recommendation listed above on crew restraint, the program has (a) outfitted the Orion seats with the latest innovations in seat and restraint systems for enhanced occupant protection; (b) implemented limb flail requirements and additional protections to ensure proper arm positioning to maintain control of the vehicle under high acceleration events; and (c) is designing suit and seat in an integrated fashion with the entire spacecraft.

Mr. Jeff Hanley, Program Manager of the Constellation Program, will be a witness at the hearing and can provide additional details on how that Program is incorporating safety and applicable human-rating requirements, as well as Astronaut Office input on launch/entry systems safety, into the Constellation program's design, development, and testing activities.

NASA's Human Rating and Safety Requirements

According to NASA's Inspector General, NASA assembled a diversified group in 2007 composed of astronauts, engineers, safety engineers, flight surgeons, and mission operations specialists to rewrite the agency's human-rating requirements, which had been embodied in NPR 8705.2A, "Human-Rating Requirements for Space Systems." As stated in the NASA Inspector General's report IG–09–016 dated May 21, 2009:

> *"This group reviewed human-rating documents from the last 45 years that were used in the development of Mercury, Gemini, Apollo, Skylab, the Space Shuttle, and the International Space Station. The lessons learned from these programs, and information from numerous books and studies, resulted in NPR 8705.2B, issued May 6, 2008."*

The stated purpose of NPR 8705.2B is "*to define and implement the additional processes, procedures, and requirements necessary to produce human-rated space systems that protect the safety of crew members and passengers on NASA space missions.*"

The NPR states that "*a human-rated system accommodates human needs, effectively utilizes human capabilities, controls hazards and manages safety risk associated with human spaceflight, and provides, to the maximum extent practical, the capability to safely recover the crew from hazardous situations. Human-rating is not and should not be construed as certification for any activities other than carefully managed missions where safety risks are evaluated and determined to be acceptable for human spaceflight.*"

The NPR further states that "*Human-rating must be an integral part of all program activities throughout the life cycle of the system, including design and development; test and verification; program management and control; flight readiness certification; mission operations; sustaining engineering; maintenance, upgrades, and disposal.*"

As to applicability, the NPR states that "*The human-rating requirements in this NPR apply to the development and operation of crewed space systems developed by NASA used to conduct NASA human spaceflight missions. This NPR may apply to other crewed space systems when documented in separate requirements or agreements.*" The NPR notes that "*The Space Shuttle, the International Space Station (ISS), and Soyuz spacecraft are not required to obtain a Human-Rating Certification in accordance with this NPR. These programs utilize existing policies, procedures, and requirements to certify their systems for NASA missions.*" The NPR is applicable to the Constellation Program.

The NPR views human-rating as consisting of three fundamental tenets:

1. Human-rating is the process of designing, evaluating, and assuring that the total system can safely conduct the required human missions.
2. Human-rating includes the incorporation of design features and capabilities that accommodate human interaction with the system to enhance overall safety and mission success.
3. Human-rating includes the incorporation of design features and capabilities to enable safe recovery of the crew from hazardous situations.

According to NASA's guidance, human-rating is an integral part of all program activities throughout the life cycle of the system, including design and development; test and verification; program management and control; flight readiness certification; mission operations; sustaining engineering; maintenance/upgrades; and disposal.

The NPR technical requirements for human-rating address system safety, crew/human control of the system, and crew survival/aborts. The requirements associated with crew survival and abort capability were established following the two previously cited Shuttle accidents. For example, the NPR states that for Earth Ascent Systems:

- *"The space system shall provide the capability for unassisted crew emergency egress to a safe haven during Earth prelaunch activities."*
- *"The space system shall provide abort capability from the launch pad until Earth-orbit insertion to protect for the following ascent failure scenarios (minimum list):*
    - *a. Complete loss of ascent thrust/propulsion*
    - *b. Loss of attitude or flight path."*
- *"The crewed space system shall monitor the Earth ascent launch vehicle performance and automatically initiate an abort when an impending catastrophic failure is detected."*

Regarding Earth ascent abort, the NPR states that:

- *"The space system shall provide the capability for the crew to initiate the Earth ascent abort sequence."*
- *"The space system shall provide the capability for the ground control to initiate the Earth ascent abort sequence."*
- *"If a range safety destruct system is incorporated into the design, the space system shall automatically initiate the Earth ascent abort sequence when range safety destruct commands are received onboard, with an adequate time delay prior to destruction of the launch vehicle to allow a successful abort."*

Once in orbit, the NPR requires the crewed space system to "*provide the capability to autonomously abort the mission from Earth orbit by targeting and performing a deorbit to a safe landing on Earth.*"

In addition, NPR 8715.3C which establishes NASA's General Safety Program Requirements, has a section entitled "*Hazardous Work Activities That Are Outside*

NASA Operational Control." The NPR states that it is NASA policy to "*document and verify that risks are adequately controlled and any residual risk is acceptable*". Applicability to commercial human space flight is cited. Specifically, Section 1.14.1 states:

> *"It is NASA policy to formally review and approve NASA participation in hazardous work activities that are outside NASA operational control as needed to ensure that NASA safety and health responsibilities are satisfied. This policy applies unconditionally to NASA participation in commercial human spaceflight where current federal regulations do not necessarily provide for the safety of spaceflight vehicle occupants. This policy is non-retroactive and applies to hazardous ground or flight activities that involve research, development, test and evaluation, operations, or training, where all five of the following conditions exist:*
>
> a. *NASA civil service personnel, Government detailees, specified contractors, or specified grantees are performing work for NASA.*
> b. *The activity is outside NASA's direct operational control/oversight.*
> c. *An assessment by the responsible NASA manager indicates there are insufficient safeguards and/or oversight in place.*
> d. *The activity is not covered by a basic contract, grant, or agreement where Federal, State, and/or local requirements address personnel safety.*
> e. *The nature of the activity is such that, if NASA were controlling it, a formal safety and/or health review would be required as part of the NASA approval process."*

In terms of responsibilities, the NASA Associate Administrator, as chair of the Agency Program Management Council, is the authority for human-rating and is responsible for certifying systems as human-rated. In this capacity, the NASA Associate Administrator makes the determination to certify a system as human-rated. Appeals for exceptions and waivers to the NPR are made to the NASA Associate Administrator. The Chief, Safety and Mission Assurance, is the Technical Authority for Safety and Mission Assurance and is responsible for assuring the implementation of safety-related aspects of human-rating.

In its 2008 Annual Report, the Aerospace Safety Advisory Board (ASAP), the congressionally established body which evaluates and provides advice on NASA's safety performance, noted changes in NPR 8705.2B from the prior guidance:

> *"The ASAP is concerned about HRR [human rating requirements] substance, application, and standardization NASA-wide.*
>
> - *After several briefings, the Panel is just beginning to fully understand the changes (e.g., in failure tolerance, inadvertent actions, redundancy, and integrated design analysis) and the implications for future system development—an index of the challenge facing NASA.*
> - *The new HRR standards move from validating compliance with mandatory failure tolerance requirements to an approach of designing to acceptable risk, but without any apparent clear and visible criteria for estimating "how safe is safe enough" for various mission categories.*
> - *A direct linkage between current standards and engineering directives is missing.*
> - *NASA training materials on the new HRR standards are still in development and should be accelerated to distribute information before new Constellation systems are developed."*

Mr. Bryan O'Connor, Chief of Safety and Mission Assurance and former astronaut, will be a witness at the hearing and can provide additional details on OSMA's latest activities associated with implementing safety-related aspects of human-rating, including addressing the ASAP's concerns. Mr. John Marshall, a member of the ASAP, will also be testifying at the hearing.

Enhancing Safety through Crew Training

As evidenced by the performance of the crew of Apollo 13 after the incident that created a serious emergency situation en route to the Moon, astronauts play a major role in ensuring human safety in space. In that situation, the crew detected, reacted, and with the help of engineers and technicians on the ground, overcame problems that mechanical systems could not. Integral to that crew's ability to improvise under difficult conditions was the training they received.

Today's astronaut training program builds on years of flight experience. Once selected as candidates, astronauts undergo a rigorous training program that ranges from basic training in generic vehicle systems to being trained to operate spacecraft systems using simulators. Survival training includes emergency egress from the Shuttle and surviving in a water or wilderness environment. As a final step, crews conduct integrated operational training with flight controllers in NASA's Mission Control Center at the Johnson Space Center.

Training for off-nominal operations is an important facet of crew training. Astronauts are acquainted with non-safety-critical failure modes and the ways to respond to them. Training for off-nominal conditions is primarily accomplished by inserting failures during simulations at which time astronauts are trained to recognize the off-nominal conditions and identify corrective measures. The level of difficulty arises when several failures are injected during simulations and crew members must perform failure analyses in an integrated manner and apply corrective procedures in sequence. Emergency training is needed for those situations where all measures identified through other forms of training cannot be used. The most critical emergencies primarily involve fire, depressurization, and toxic contamination. The goal of NASA's training is to have a trained astronaut who is able to respond and assist in any contingency situation that may arise.

Safety Considerations in NASA's Selection of Space Exploration Vehicles

In January 2004, President Bush announced his *Vision for Space Exploration*, which called for NASA to safely return the Space Shuttle to flight; complete the International Space Station (ISS); return to the Moon to gain experience and knowledge for human missions beyond the Moon, including Mars; and increase the use of robotic exploration to maximize our understanding of the solar system and pave the way for more ambitious human missions. Congressional support for a new direction in the Nation's human spaceflight program was clearly articulated in the 2005 NASA Authorization Act. Specifically, the Act directed the NASA Administrator "*to establish a program to develop a sustained human presence on the Moon, including a robust precursor program, to promote exploration, science, commerce, and United States preeminence in space, and as a stepping-stone to future exploration of Mars and other destinations. The Administrator was further authorized to develop and conduct appropriate international collaborations in pursuit of these goals*."

Shortly after Dr. Michael Griffin was named the new NASA Administrator in April 2005, he set out to restructure the Exploration Program by giving priority to accelerating the development of the Crew Exploration Vehicle (CEV) to reduce or eliminate the anticipated gap in U.S. human access to space following the retirement of the Space Shuttle. Specifically, he established a goal for the CEV to begin operation as early as 2011and to be capable of ferrying crew and cargo to and from the ISS. He also decided to focus on existing technology and proven approaches for exploration systems development. In order to reduce the number of required launches for exploration missions and to ease the transition after Space Shuttle retirement in 2010, the Administrator, consistent with the congressional guidance contained in the NASA Authorization Act of 2005, directed the Agency to examine the cost and benefits of developing a Shuttle-derived Heavy-Lift Launch Vehicle to be used in lunar and Mars exploration. As a result, the Exploration Systems Architecture Study (ESAS) team was established to determine the best exploration architecture and strategy to implement these changes.

In November 2005, NASA released the results of the ESAS, an initial framework for implementing the VSE and a blueprint for the next generation of spacecraft to take humans back to the Moon and on to Mars and other destinations. ESAS made specific design recommendations for a vehicle to carry crews into space, a family of launch vehicles to take crews to the Moon and beyond, and a lunar mission "architecture" for human lunar exploration. ESAS presented a time-phased, evolutionary architectural approach to returning humans to the Moon, servicing the ISS after the Space Shuttle's retirement, and eventually transporting humans to Mars. Under the 2005 ESAS plan, a Crew Exploration Vehicle (CEV and now called Orion) and Crew Launch Vehicle (CLV and now called Ares I) development activities would begin immediately, leading to the goal of a first crewed flight to the ISS in 2011. Options for transporting cargo to and from the ISS would be pursued in cooperation with industry, with a goal of purchasing transportation services commercially. In 2011, the development of the major elements required to return humans to the Moon would begin—the lunar lander (now called Altair), heavy lift cargo launcher (now called Ares V), and an Earth Departure Stage vehicle. These elements would be developed and tested in an integrated fashion, with the internal goal of a human lunar landing in 2018. When resources needed to achieve the 2011 goal for CEV operations were not forthcoming, the Constellation Program established a formal target of 2015 for initial CEV flights to the ISS.

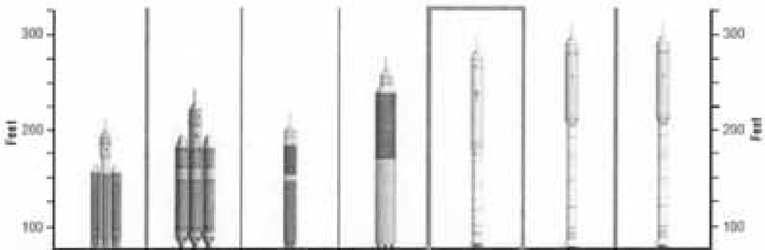
According to the ESAS report, the team's major trade study was a detailed examination of the relative costs, schedule, reliability, safety, and risk of using DoD's Evolved Expendable Launch Vehicle (EELV) and Shuttle derived launchers for crew and cargo missions. Among its operational ground rules and assumptions was the CAIB finding on the desirability of an architecture that will "*separate crew and large cargo to the maximum extent practical*".

The EELV options examined for suitability for crew transport by the ESAS team were derived from the Delta IV and Atlas V families. The team found that:

- None of the medium versions of either vehicle had the capability to accommodate CEV lift requirements. Augmentation of the medium-lift class systems with solid strap-on boosters was thought by the team to pose an issue for crew safety because of small strap-on Solid Rocket Motor reliability.
- Both vehicles required modification for human-rating, particularly in the areas of avionics, telemetry, structures, and propulsion systems.
- Both Atlas- and Delta-derived systems required new upper stages to meet the lift and human rating requirements.
- Both Atlas and Delta single-engine upper stages fly highly lofted trajectories, which can produce high deceleration loads on the crew during an abort an, in some cases, can exceed crew load limits as defined by NASA standards.

CLV options derived from Shuttle elements focused on the configurations that used a Reusable Solid Rocket Booster (RSRB), either as a four-segment version nearly identical to the RSRB flown today or a higher-performance five-segment version of the RSRB. The team sought to develop options that could meet the lift requirement using a four-segment RSRB. To achieve this, a 500,000-lbf vacuum thrust class propulsion system would be needed. Two types of upper stage engines were assessed. According to ESAS, the option chosen, including using the Space Shuttle Main Engine (SSME) for the upper stage, was selected due to projected lower cost, higher safety/reliability, its ability to utilize existing human-rated systems and infrastructure and the fact that it gave the most straightforward path to a heavy lift launch vehicle for cargo. Subsequently, to achieve lower recurring costs, the rocket motor powering the upper stage was changed to a variant of the J–2S Saturn-era motor and now called J–2X.

The following chart from the ESAS report summarizes the team's findings with regards to CLV options and compares these options on the basis of Loss of Mission (LOM) and Loss of Crew (LOC) probabilities:



	Human-Rated Atlas V/New US	Human-Rated Delta IV/New US	Atlas Phase 2 (5.4-m Core)	Atlas Phase X (8-m Core)	4 Segment RSRB with 1 SSME	5 Segment RSRB with 1 J-2S	5 Segment RSRB with 4 LR-85
Payload (28.5°)	30 mT	28 mT	26 mT	70 mT	25 mT	26 mT	27 mT
Payload (51.6°)	27 mT	23 mT	25 mT	67 mT	23 mT	24 mT	25 mT
DDT&E*	1.18**	1.03	1.73**	2.36	1.00	1.3	1.39
Facilities Cost	.92	.92	.92	.92	1.00	1.00	1.00
Average Cost/Flight*	1.00	1.11	1.33	1.71	1.00	.96	.96
LOM (mean)	1 in 149	1 in 172	1 in 134	1 in 79	1 in 460	1 in 433	1 in 182
LOC (mean)	1 in 957	1 in 1,100	1 in 939	1 in 614	1 in 2,021	1 in 1,918	1 in 1,429

LOM: Loss of Mission LOC: Loss of Crew US: Upper Stage RSRB: Reusable Solid Rocket Booster

* *All cost estimates include reserves (20% for DDT&E, 10% for Operations), Government oversight/full cost; Average cost/flight based on 6 launches per year.*

** *Assumes NASA has to fund the Americanization of the RD-180. Lockheed Martin is currently required to provide a co-production capability by the USAF.*

Source: NASA (ESAS)

With regards to crew safety, as shown in the table above, analysis by the ESAS team showed that the initially recommended concept had a mean LOC of 1 in 2,021 and the current design had a mean LOC of 1 in 1,918. As such, initially both concepts met the recommendations from the CAIB and the Astronaut's Office that a Shuttle replacement have at least a LOC of 1 in 1,000 missions. In comparison, the other options ranged from 1 in 614 to 1 in 1,100. The selected CLV design, which later became known as Ares I, was also projected to offer significant improvement in Loss of Mission over other launch options.

In his presentation to the Augustine Committee on July 29, 2009, Dr. Joseph Fragola, a member of the ESAS team and Vice President of Valador, Inc., told the Committee that this meant that "*Ares I is at least a factor of 2 safer from a loss of crew perspective and in some cases closer to a factor of 3*." In a recent conversation between Subcommittee staff and Dr. Fragola, he indicated that the ESAS team was more interested in establishing the relative risk among the options and not in their absolute risk values. According to NASA, the recommended concept's lower LOC estimate is a direct reflection of the use of a simpler design and fewer moving parts characteristic of a single solid propellant first stage. The recommended concept was accepted and formed the basis of the Ares I crew launch vehicle.

Dr. Fragola will be a witness at the hearing and can provide additional details on the ESAS Team's analysis of how alternative configurations compared with regards to loss of crew and loss of mission projections.

Safety Oversight by the Aerospace Safety Advisory Panel

Since it was established in 1968 by Congress, the Aerospace Safety Advisory Panel (ASAP) has been evaluating NASA's safety performance and advising the agency on ways to improve that performance. The Panel consists of members appointed by the NASA Administrator and is comprised of recognized safety, management, and engineering experts from industry, academia, and other government agencies.

The ASAP reports to the NASA Administrator and Congress. The Panel was established by Congress in the aftermath of the January 1967 Apollo 204 spacecraft fire. The Panel's statutory duties, as prescribed in Section 6 of the NASA Authorization Act of 1968, Public Law 90–67, 42 U.S.C. 2477 are as follows:

> *"The Panel shall review safety studies and operations plans that are referred to it and shall make reports thereon, shall advise the Administrator with respect*

to the hazards of proposed operations and with respect to the adequacy of proposed or existing safety standards, and shall perform such other duties as the Administrator may request."

The Panel was authorized in Section 106, Safety Management, of the *National Aeronautics and Space Administration Authorization Act of 2005*, [P.L. 109–155]. The ASAP bases its advice on direct observation of NASA operations and decision-making. The Panel provides an annual report. In addition to examining NASA's management and culture related to safety, the report also examines NASA's compliance with the recommendations of the CAIB. Advice from the ASAP on technical authority, workforce and risk management practices has been provided to the NASA Administrator.

Critical human space flight safety issues the Panel identified in its 2008 Annual Report included the proposed extension of the Space Shuttle Program; the use of commercial transportation sources; the safety and reliability of the Russian Soyuz spacecraft; an opportunity to hardwire safety into the fabric of the Constellation Program; the suitability of agency management approaches; and technical Standards Program focused on safety and risks.

In his testimony at the Subcommittee's June 2009 hearing on "*External Perspectives on the FY 2010 NASA Budget Request and Related Issues*", the ASAP witness stated that while the Panel endorses and supports investing in a Commercial Orbital Transportation Services (COTS) program, it believes "*at this juncture that NASA needs to take a more aggressive role articulating human rating requirements for the COTS Program since most programs are well underway. To do otherwise may, at a later time, pressure NASA into accepting a system for expediency that is below its normal standard for safety*". In its 2008 report, the ASAP stated:

"COTS vehicles currently are not subject to the Human-Rating Requirements (HRR) standards and are not proven to be appropriate to transport NASA personnel."

and

"The capability of COTS vehicles to safely dock with the ISS still must be demonstrated."

In addition to its annual report, the Panel submits Minutes with recommendations to the NASA Administrator resulting from its quarterly meetings. The Panel held its Third Quarterly Meeting in July 2009 [the Panel's most recent Quarterly Meeting was held on October 22, 2009 at the Kennedy Space Flight Center]. At that meeting, the Panel's official minutes referenced the panel's continuing concerns regarding the application of human rating criteria to commercial crew transportation services:

"As far as the safety issues, they basically boil down to expanding the cargo capability to include crew. If that is done, the traditional method would be to apply full human rating criteria initially at the beginning of the program's development. However, thus far NASA has consciously chosen to not use a traditional approach, and there yet have been any performance requirements identified to put crews on board a COTS vehicle. The Panel previously had made a recommendation regarding this issue and continues to be perplexed as to why NASA has delayed this important action."

"The Panel has addressed its concern in its previous quarterly and annual reports. The issue is becoming more focused and more urgent. The prospect of a COTS delivery of cargo to space is organizationally and politically simpler than crew transport. The issue of human rating with COTS and the delivery of NASA astronauts into space is the primary concern. Admiral Dyer [Chairman of the ASAP] *noted that the Panel remains concerned that in the probing of this question, NASA looks to the FAA, which doesn't have the institutional history and people to speak clearly to the topic. This issue represents an opportunity for improved interagency performance."*

Admiral Dyer also noted at the July meeting that "*If the* [commercial] *vehicle is being designed to be a cargo hauler, that is a different mission and a different set of designs than a crew transporter.*" Mr. John Frost, a Panel member, added that "*the human rating requirements for the Agency are built around the design process and those processes are ongoing now at the COTS contractors. It would be problematic to come back later to put these requirements into a process that is already complete."*

As mentioned above, Mr. John Marshall, a member of the ASAP, will be a witness at the hearing and can provide additional details on the Panel's work and safety-related concerns.

Commercially Provided Crew and Cargo Space Transportation Services

At present there are no commercially owned and operated human space transportation systems in service. Only one company, Scaled Composites, has successfully launched and returned humans safely to space and back on suborbital flights in an experimental spacecraft [SpaceShipOne] and launch system. Virgin Galactic intends to purchase operational vehicles from Scaled Composites and enter into commercial operations. Originally slated to enter into commercial operations in 2007, they are currently projecting a 2011 debut for SpaceShipTwo's suborbital flight operations. Several other companies/ventures also have plans to take paying passengers on suborbital 'tourism' trips, but have not yet flown any craft to space with humans aboard.

Along with space tourism, the 'NewSpace' community has stated that suborbital services will be able to provide opportunities for suborbital science experiments, suborbital travel and package delivery. According to members of this 'Newspace' community, after carrying out suborbital business operation, a number of them have hopes of being able to undertake orbital operations in the future. However, there are a number of regulatory concerns and technical issues that would have to be addressed, as well as significant investments made, before such a future could be realized. Orbital flight operations are considered significantly more challenging than suborbital flight operations.

Commercial Orbital Transportation Services Demonstrations

Under the Commercial Orbital Transportation Services (COTS) Demonstration project, NASA is helping industry develop and demonstrate cargo space transportation capabilities. According to NASA, the COTS project provides a vehicle for industry to lead and direct its own efforts with NASA providing technical and financial assistance. NASA will invest approximately $500 million toward cargo space transportation flight demonstrations. There are currently two funded participants in the COTS demonstration project, namely Space Exploration Technologies (SpaceX) and Orbital Sciences Corporation (Orbital).

According to NASA, as of September 16, 2009, SpaceX had completed 15 of 22 milestones and has received a total of $243 million in payments, with $35 million available for the remaining milestones. Milestone tasks range from Project Plan Review to Flight Demonstration. SpaceX has begun manufacturing the flight Dragon capsule and Falcon 9 launcher to be used for the COTS demonstration flight 1. Under the terms of the current Space Act Agreement, SpaceX was scheduled to complete its first demonstration flight in June 2009 (The initial Space Act Agreement between NASA and SpaceX was signed in August 2006 and called for a scheduled first demonstration flight by September 2008).

To allow additional time for Dragon and Falcon 9 manufacturing and testing programs, SpaceX indicated in June 2009 that it expected to complete its first demonstration flight in January 2010, with the second and third flights then planned for June 2010 and August 2010, respectively. However, making the first COTS demonstration flight in January 2010 will be challenging. According to an October 29th, 2009 *Space News* article, development of the Falcon 9 rocket—along with that of its smaller sibling, the Falcon 1—has taken longer than SpaceX expected. The same *Space News* article reports that SpaceX's range request for the inaugural Falcon 9 flight made for February 2010 conflicts with another already approved launch. This is significant because of the relationship between the Falcon 9 inaugural flight and the first COTS demonstration flight. The first COTS flight must receive an FAA license before it is launched. In its June 2009 briefing to the Augustine Committee, SpaceX projected that the first COTS demonstration flight would occur 2 months after the inaugural Falcon 9 flight. The smaller Falcon 1, which is designed for transport of satellites to low Earth orbit and is not part of the COTS project, has encountered its share of developmental challenges. In July 2009, Falcon 1 successfully delivered the Malaysian RazakSAT satellite to orbit. Prior to a successful test flight in September 2008 at which time a dummy payload reached orbit, there had been three unsuccessful Falcon 1 flights, the first of which occurred in March 2006.

As of September 16, 2009, NASA says that Orbital has completed 10 of its planned 19 milestones and has received a total of $120 million to date with an additional $50 million available for future milestones. The Orbital demonstration flight is currently planned for March 2011 due to the company's decision to change its cargo transportation architecture from an unpressurized (external) cargo system to a pressurized (internal) cargo system. The initial Space Act Agreement signed in February 2008 had a scheduled first demonstration flight date of December 2010.

According to NASA, the agency will not pay for any milestone until the milestone is successfully completed per the Space Act Agreement and approved by the agency.

Should a milestone be missed, NASA says that it will evaluate partner progress made and recommend future actions that are in the best interest of the government.

Commercial Resupply Services

In December 2008, NASA awarded contracts to two companies for the delivery of cargo to the ISS after the retirement of the Space Shuttle. The successful bidders for Commercial Resupply Services (CRS) contracts were Orbital and SpaceX, the two COTS demonstration program funded participants. NASA says that it awarded two contracts to mitigate the risk of being dependent on a single contractor. A protest lodged to the Government Accountability Office (GAO) in January 2009 by PlanetSpace, Inc, an unsuccessful bidder, was subsequently denied by GAO in April 2009.

The scope of the CRS effort includes the delivery of pressurized and/or unpressurized cargo to the ISS and the disposal or return of cargo from the ISS. In addition, there are non-standard services and special task assignments and studies that can be ordered to support the primary standard resupply service. NASA ordered 8 flights valued at $1.88 billion from OSC and 12 flights valued at $1.59 billion from SpaceX. According to NASA's press release announcing the contracts, the maximum potential value of each contract is $3.1 billion. Based on known requirements, the combined value of the two awards is projected at $3.5 billion.

Each award under the contracts calls for the delivery of a minimum of 20 metric tons of cargo to the ISS, as well as the return or disposal of 3 metric tons of cargo from the orbiting complex. The CRS contracts are firm-fixed price, Indefinite Delivery Indefinite Quantity procurements with a period of performance from January 1, 2009, through December 30, 2015.

Commercial Crew Transportation Services

Although NASA currently has no contracts for the transportation of crew by commercially provided space transportation services [which do not at present exist], it has recently applied funds from the American Recovery and Reinvestment Act of 2009 to work on the Commercial Crew and Cargo Program:

- A modification to the Bioastronautics contract with Wyle Integrated Science & Engineering Group was made to develop a set of human system integration requirements for application to commercial spacecraft in support of NASA's Commercial Crew and Cargo Program. According to NASA, the human system integration requirements developed under this task order will be based on a review of existing Human Rating requirements, Spaceflight Human Systems Standards, Constellation Program requirements, Commercial Crew and Cargo Program Office operational concepts and requirements, and the Johnson Space Center Space Life Sciences Directorate Human Interface Design Handbook.
- NASA's Commercial Crew and Cargo Program is applying Recovery Act funds to solicit proposals from all interested U.S. industry participants to mature the design and development of commercial crew spaceflight concepts and associated enabling technologies and capabilities. NASA plans to use its Space Act authority to invest up to $50 million dollars in multiple competitively awarded, funded agreements. This activity is referred to as Commercial Crew Development, or CCDev.

Commercial Spaceflight Federation

According to the Commercial Spaceflight Federation (CSF), its mission is to "*promote the development of commercial human spaceflight, pursue ever higher levels of safety, and share best practices and expertise throughout the industry. CSF member organizations include commercial spaceflight developers, operators, and spaceports*". The Commercial Spaceflight Federation is governed by a board of directors, composed of the member companies' CEO-level officers and entrepreneurs.

The Federation recently voiced strong support for the report by the Review of U.S. Human Space Flight Plans Committee which included in its options the creation of a Commercial Crew program to develop commercial capabilities to transport crew to the International Space Station.

Mr. Bretton Alexander, President of the Commercial Spaceflight Federation, will be a witness at the hearing and can provide details related to commercial provider plans to human rate commercial space transportation systems as well as the commercial space industry expectations of how NASA's safety standards and requirements would be applied to commercially crewed spacecraft.

Chairwoman GIFFORDS. Good morning. This hearing has now come to order.

This hearing this morning is the latest in a series of hearings that this Subcommittee is holding on a critical issue, an issue that we will have to take into consideration as Members of Congress and also the White House in considering the future direction and funding for NASA. In many ways, the topic of today's hearing is one of the most important issues confronting us, namely, how to ensure the safety of those brave men and women whom the Nation sends into space to explore and push back the boundaries of the space frontier. Of course, I am not under any illusion that human spaceflight can ever be risk-free. Nothing in life, of course, is.

The Apollo 1 fire, the *Challenger*, *Columbia*, these fatal accidents, as well as other spaceflight incidents that could have led to loss of life, have driven that point home in stark and tragic terms. Indeed, this Subcommittee is holding today's hearing because we need to be sure that any decision being contemplated by the White House or by the Congress are informed by our best understanding of the fundamental crew safety issues facing our human spaceflight program. And in making those decisions, we should not let either advocacy or unexamined optimism replace probing questions and thoughtful analysis.

That is why the Subcommittee has invited this distinguished panel of witnesses to appear before us today. We need the benefit from your perspective and experience as we examine critically important questions that Congress will need to have answered if we are to assess the various proposals that are being put forth.

Much has been said about the potential future plans for exploration in recent months, but there has been precious little discussion about safety. Today's hearing is the first step in rectifying that situation.

Let me list just a few questions that we hope our witnesses will answer today. As several of the witnesses have put in their prepared testimony, the Constellation program strove to respond to the recommendations of the Columbia Accident Investigation Board that the design of the system that replaces the shuttle should give overriding priority to crew safety. The result is a system that is calculated to be significantly safer than the space shuttle, and two to three times safer than the alternative approaches considered by NASA. Given that, we hope that our witnesses as to whether—we will hear from them whether or not they believe that the burden of proof should be put on those who would propose alternatives to Constellation to demonstrate that their systems will be at least as safe as Ares and Orion. Alternatively, we would like to hear whether or not it would be acceptable to reduce the required level of crew safety on commercially provided crew transport services used to transport U.S. astronauts much below what looks likely to be achievable in the Constellation program.

In addition, we need to hear our witnesses' views on whether the timetable suggested for the availability of commercial crew transport services is realistic or not. That is, when one takes into account all of the steps, not just those that are explicitly safety related, that will need to be taken before the first NASA astronaut can ride to the International Space Station on an operational commercial crew vehicle, do our witnesses believe that such vehicles will be available in time to meet a significant fraction of NASA's ISS crew transfer and crew rescue needs prior to 2020 or not. Similarly, given those required steps, do our witnesses believe that would-be commercial crew transport service providers will be able to garner sufficient revenues from non-NASA passenger transport services to remain viable over that same time period or not.

I ask these questions, and we will hear other questions of course from our members, because it is going to be difficult to make reasoned judgments about the wisdom of investing significant taxpayer dollars in would-be commercial providers or of altering Congress's commitment to the existing Constellation program in the absence of clear answers.

Finally, what do our witnesses consider to be the most important safety-related issues that will need to be addressed if we are to make our decisions on the future of NASA's human spaceflight and exploration program, and, at the end of the day, what will Congress need to do to have the assurance that we have done all we can to ensure the safety of our Nation's future human spaceflight activities? This is not a hypothetical question. It is fundamental for fulfilling our responsibilities as Members of Congress. With so much for our Subcommittee to consider, I am comforted that we have a very distinguished panel who can speak with conviction and knowledge about safety issues and everything that needs to be considered.

So I welcome all of you to today's hearing. All of us here of course are passionate about space, whether in the private sector or the public sector. We want the best possible future for our Nation in its space endeavors. I hope that this morning's hearing will help us chart a productive and a responsible path forward.

And finally, I would be remiss if we did not acknowledge the unique contributions of one of our witnesses to the advancement of safety in human spaceflight, and I want to welcome each of you to our hearing but particularly Gen. Tom Stafford, a veteran of Gemini, Apollo, Apollo-Soyuz, Shuttle Return to Flight, and countless other space flight efforts. He can speak as a true national hero and an authority.

So in closing, I know that my colleagues join me in saying that we all owe General Stafford a great amount of debt for everything you have done for our country and we are honored, sir, that you are here with us today. Thank you.

[The prepared statement of Chairwoman Giffords follows:]

PREPARED STATEMENT OF CHAIRWOMAN GABRIELLE GIFFORDS

Good morning. This morning's hearing is the latest in a series of hearings that this subcommittee is holding on critical issues that the White House and Congress need to consider as decisions are made on the future direction and funding for NASA. In many ways, the topic of today's hearing is one of the most important issues confronting us—namely, how to ensure the safety of those brave men and women whom the nation sends into space to explore and push back the boundaries of the space frontier. Of course, I am under no illusions that human spaceflight can ever be made risk-free. Nothing in life is.

The Apollo 1 fire, the *Challenger* and *Columbia* fatal accidents, as well as other space flight incidents that could have led to loss of life, have driven that point home in stark and tragic terms. Indeed, this subcommittee is holding today's hearing because we need to be sure that any decisions being contemplated by the White House and Congress are informed by our best understanding of the fundamental crew safety issues facing our human space flight program. And in making those decisions, we should not let either advocacy or unexamined optimism replace probing questions and thoughtful analysis.

That is why the subcommittee has invited this distinguished set of witnesses to appear before us today. We need the benefit of your perspectives and experience as we examine critically important questions that Congress will need to have answered if we are to assess the various proposals that have been put forth.

Much has been said about potential future plans for exploration in recent months, but there has been precious little discussion of crew safety Today's hearing is a first step in rectifying that situation.

Let me list just a few of the questions that we would like our witnesses to address today. As several of the witnesses at today's hearing will testify, the Constellation program strove to respond to the recommendation of the *Columbia* Accident Investigation Board that "The design of the system [that replaces the Shuttle] should give overriding priority to crew safety . . ." The result is a system that is calculated to be significantly safer than the Space Shuttle, and two to three times safer than the alternative approaches considered by NASA. Given that, we hope to hear from our witnesses as to whether they believe that the burden of proof should be put on those who would propose alternatives to the Constellation program to demonstrate that their systems will be at least as safe as Ares/Orion. Alternatively, do they think it would it be acceptable to reduce the required level of crew safety on commercially provided crew transport services used to transport U.S. astronauts much below what looks to be achievable in the Constellation program?

In addition, we need to hear our witnesses' views on whether the timetable suggested for the availability of commercial crew transport services is realistic or not.

That is, when one takes into account all of the steps—not just those that are explicitly safety-related—that will need to be taken before the first NASA astronaut can take a ride to the ISS on an operational commercial crew vehicle, do our witnesses believe that such vehicles will be available in time to meet a significant fraction of NASA's ISS crew transfer and crew rescue needs prior to 2020 or not? Similarly, given those required steps, do our witnesses believe that would-be commercial crew transport services providers will be able to garner sufficient revenues from non-NASA passenger transport services to remain viable over that same time period or not?

It will be difficult to make reasoned judgments about the wisdom of investing significant taxpayer dollars in would-be commercial providers or of altering Congress's commitment to the existing Constellation program in the absence of clear answers to those questions.

Finally, what do our witnesses consider to be the most important safety-related issues that will need to be addressed as we make our decisions on the future of NASA's human space flight and exploration program.

And, at the end of the day, what will Congress need to do to have the assurance that we have done all we could to ensure the safety of the nation's future human space flight activities? That is not a hypothetical question. It is fundamental to fulfilling our responsibilities as Members of Congress. With so much for this subcommittee to consider, I am comforted by the realization that we have a very distinguished panel who can speak with conviction and knowledge about the safety issues that will need to be considered.

I want to welcome each of you to today's hearing. All of us who are passionate about space, whether in the private sector or the public sector, want the best possible future for our nation in its space endeavors. I hope that this morning's hearing will help us chart a productive and responsible path forward.

Finally, I would be remiss if I did not acknowledge the unique contributions of one of our witnesses to the advancement of safety in human space flight. I want to welcome each of you to today's hearing. Lt. Gen. Thomas P. Stafford, a veteran of the Gemini, Apollo, Apollo-Soyuz, Shuttle Return-to-Flight, and countless other space flight efforts, can speak with authority on safety issues—he has lived them. He is a true national hero.

So in closing, I know that my colleagues join me in saying that we owe Gen. Stafford and the other pioneers of human space flight a debt of gratitude. Without their efforts—and bravery—NASA would not have made the safety advances that it has.

Chairwoman GIFFORDS. The Chair now recognizes Mr. Olson for his opening statement.

Mr. OLSON. Madam Chairwoman, I would like to yield to the ranking member of our full Committee if he is ready to make his statement at this time.

Mr. HALL. I don't know how ready I am but I will take a shot at it.

I really enjoyed, Madam Chairman, your speech and I agree with everything you have said. You are in an unusual position to know what you are talking about and have more than just a passing interest and more than a committee chairman's interest in the safety that we are going to talk about today, and I want to thank you for allowing me to make the statement and for holding this hearing. It is one of the topics that I think I am most passionate about and that is the safety of our crews. It simply has to be at the heart of everything NASA does in space.

Also, I want to sincerely thank all of today's witnesses for taking the time and effort. I know it takes time. You prepared yourself back during your lifetime for this presentation to us and you are the very type of citizen that comes here that gives us information from which we glean the ingredients that go into the bills, and we know it takes your time. Your time is valuable and you didn't suffer to get here but you paid the price to get here. We are very honored to have each one of you. I want to sincerely thank all of you for taking the time and effort.

I especially want to welcome a friend of mine here and have the liberty of saying a word or so about Gen. Tom Stafford. He is a good friend. He is a national hero. I have relied on his advice for many years. He is the kind of guy that I call and get him out of the garden or wherever he is, the library, wherever he may be, but I have called on him for a lot of information on many occasions and we have exchanged personal letters through the years, most recently when he chaired the Stafford-Covey Return to Flight Task Force established to ensure that the Columbia Accident Investigation Board's recommendations were carried out.

And we have a lot of important issues to cover today. The Columbia Accident Board gave NASA many safety recommendations and principles to follow in the design of future launch vehicles. In May of 2004, after carefully reviewing the findings, the Astronaut Office published their position on the safety of future launch systems. One recommendation was to include a crew escape system module as part of any new launch vehicle. In the NASA authorization bill of 2005, many of us worked together to ensure that such a system was part of NASA's plans for the next human exploration vehicle, and I know we all will continue to insist that this remains the case.

Much of what I say today is in a piece in Monday's edition of Space News. Madam Chair, I would like to ask unanimous consent to include a copy of the May 4, 2004, Astronaut Office position on future launch system safety and throw in a copy of my November 30th Space News editorial into the record.

[The information follows:]

National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas
77058

Reply to Attn of: CB-04-044 May 4, 2004

TO: CA/Director, Flight Crew Operations

FROM: CB/Chief, Astronaut Office

SUBJECT: Astronaut Office Position on Future Launch System Safety

The Columbia disaster has precipitated a thorough reevaluation of all aspects of space flight. The accompanying paper presents the Astronaut Office position on launch vehicle safety for the next generation of human-rated spacecraft.

Kent V. Rominger

Enclosure

Astronaut Office Position on Future Launch System Safety

Executive Summary

The Columbia accident, the selection of a booster for the Orbital Space Plane (OSP), and NASA's recently renewed interest in exploring beyond low Earth orbit have led the Astronaut Office to reexamine its views on launch system safety. Although flying in space will always involve some measure of risk, it is our consensus that an order-of-magnitude reduction in the risk of loss of human life during ascent, compared to the Space Shuttle, is both achievable with current technology and consistent with NASA's focus on steadily improving rocket reliability, and should therefore represent a minimum safety benchmark for future systems. To reach that target, the Astronaut Office offers the following recommendations.

The Astronaut Office recommends that the next human-rated launch system add abort or escape systems to a booster with ascent reliability at least as high as the Space Shuttle's, yielding a predicted probability of 0.999 or better for crew survival during ascent. The system should be designed to achieve or exceed its reliability requirement with 95% confidence.

The Astronaut Office recommends that new human-rated launch vehicle programs follow guidelines, such as those given in the Columbia Accident Investigation Board (CAIB) Report and NASA's Human Rating Requirements (NPG 8705), for safety-conscious management, requirements definition, concept development, and design selection.

The Astronaut Office recommends that NASA specify and maintain a set of formal, standardized, complete methods and processes to be used in predicting the reliability of human-rated spacecraft, and identify or create an independent body to verify those analyses.

The Astronaut Office recommends that the test program for the next human-rated launch system demonstrate its reliability through vigorous ground and flight testing of components and systems. The value of each test should be leveraged by proving a safe envelope larger than that expected during operations and by using flight data to validate system reliability models. After completion of the formal test program, the vigilance applied during testing to data gathering, analysis, and flight constraints should continue to be applied during operations. Reliability should be continuously reassessed.

The Astronaut Office believes that the next human-rated spacecraft must include a robust full-envelope abort or escape system. The safety of the overall system depends on the reliability of both the booster and the abort or escape system. As with the rocket itself, the abort or escape system reliability must be proven through flight testing.

I. Introduction

Flying in space will always involve some measure of risk. Astronauts are willing to accept significant risks to further the cause of space exploration. Nevertheless, the Astronaut Office believes that future spacecraft can and should be much safer than present systems.

The CAIB, in its 2003 report, advised NASA to adopt flight safety as its "overriding priority." In hearings following the loss of Columbia, members of Congress agreed with that recommendation, emphasizing that improved safety is essential to maintaining NASA's credibility with both the public and Congress.

Shortly after the Columbia accident, the OSP Program released its Level 1 Requirements and Operational Concepts. These stated in part that, "The vehicle(s) shall initially launch on an [expendable launch vehicle] ELV," referring to the Atlas V and Delta IV ELVs. These rockets belong to a family of vehicles with a success rate of 0.975. Even with extensive modifications, they may never achieve a meaningfully higher success rate.[1] For comparison, the success rate of the Space Shuttle if viewed solely as a launch vehicle is 0.991 (one ascent failure in 113 flights, counting the Columbia accident as an entry failure because it achieved a safe orbit after launch).

Although history has shown that deadly accidents can occur during any phase of flight, ascent still poses a major risk to human life. If we wish to send explorers into space on increasingly ambitious missions, we must first solve the problem of putting humans into orbit more safely than is possible with our current launch systems.

The Columbia accident, the selection of a booster for the OSP, and NASA's recently renewed interest in exploring beyond low Earth orbit have led the Astronaut Office to reexamine its views on launch system safety. Although flying in space will always involve some measure of risk, it is our consensus that an order-of-magnitude reduction in the risk of loss of human life during ascent, compared to the Space Shuttle, is both achievable with current technology and consistent with NASA's focus on steadily improving rocket reliability, and should therefore represent a minimum safety benchmark for future systems.

II. Flight Safety and Reliability

Flight safety means protecting the lives of the crew as the top priority, above cost, manpower, reusability, adherence to schedule, and all other considerations, given that we are undertaking a dangerous mission and that our resources are finite.

Flight safety is not just a philosophical viewpoint. It is also a measurable quantity: the reliability of the systems upon which the crew's safety depends. But according to reliability theory,[2] it is not possible to measure a vehicle's reliability exactly. Instead, the probability of a safe flight must be estimated using mathematical models, flight history, or a combination of both.

In this paper, we define ascent as the time from crew arrival at the launch pad until insertion into an orbit that is safe for at least 24 hours, or, in cases where such an orbit is not reached, until crew recovery by rescue forces on Earth. We will use three statistical definitions of ascent reliability: predicted reliability, success rate, and demonstrated reliability.

Predicted reliability is an estimate of reliability, made in the absence of sufficient flight data, through the use of probabilistic risk assessment or other trustworthy modeling techniques. Its accuracy is limited because it relies on an incomplete understanding of the machine and its environment and usually takes into account only known failure modes. As flight data becomes available, it can be included in the models to improve the accuracy of reliability predictions.

A rocket's success rate is the number of times it has safely reached orbit, divided by the number of times it has been launched. For piloted missions, we count a flight reaching an incorrect but safe orbit as a success, since it does not threaten the lives of the crew even if the mission is lost. Success rate is not the same as reliability. But with enough launches the success rate will gradually become an accurate estimate of reliability.

Demonstrated reliability is an estimate of reliability based on the success rate, with allowances for statistical uncertainty.

Even a "mature" launch system with a long flight history has significant uncertainty in its reliability. To reflect that uncertainty, every reliability estimate must include a confidence level, which allows for the possibility that a rocket's modeled performance or existing safety record, because of analytical errors or random chance, does not reflect the truth. A standard confidence level is 95%, meaning that there is only a 5% chance that the system's real reliability is outside the bounds of the estimate.[3] A lower confidence level means a greater probability that the actual value of reliability falls outside the range of the estimate. For rockets carrying people, where low reliability is of greatest concern, a reduced confidence level corresponds to a greater likelihood of unrecognized danger.

Demonstrated reliability estimates at 95% confidence will be very low for new systems when the number of flights is small. This is because even an untrustworthy system can succeed a few times by random chance. It is just this kind of chance that the confidence level is intended to compensate for. (Confidence levels are less important if data from hundreds or thousands of flights is available to reduce the statistical uncertainty in the reliability estimate to an acceptably low value. Such a rich test history is characteristic of airplane programs, but not of launch systems in the past or near future.) Note that the Shuttle was declared "operational" at a time when its demonstrated reliability could only be said to be better than 0.473 with 95% confidence.

We now apply these concepts to the reliability of future human-rated launch systems. As we discuss below, adding abort or escape systems to a booster with an ascent reliability at least as high as the Space Shuttle's could yield a future launch system with an order-of-magnitude less ascent risk than Shuttle. Such a system, which the Astronaut Office believes is feasible using present technology and production processes, would answer the call for meaningfully improved flight safety as called for by Congress, the CAIB,[4] and the Astronaut Office.[5] It is also consistent with the ascent risk requirement accepted by the former OSP Program. This new safety benchmark corresponds to a predicted probability of 0.999 or better for crew survival during ascent. If flown enough times, it should demonstrate the same reliability. To ensure that a new system achieves its safety requirement, it should be designed to meet or exceed that value with the standard 95% confidence.

The Astronaut Office recommends that the next human-rated launch system add abort or escape systems to a booster with ascent reliability at least as high as the Space Shuttle's, yielding a predicted probability of 0.999 or better for crew survival during ascent. The system should be designed to achieve or exceed its reliability requirement with 95% confidence.

III. Managing and Designing for Flight Safety

Designing significantly safer space vehicles requires adopting flight safety as the overarching figure of merit and implementing measures that have been shown to minimize risk, including those outlined in the CAIB Report.[4] Practices of safety-conscious flight programs include the following: Systems should be assumed to be unsafe until proven otherwise. Waivers should not be accepted without rigorous technical justification. Expert advice from outside the organization should be sought and heeded to assess program management, vehicle design, construction, test, and operations. Safety must never be compromised by cost, schedule, or other considerations. The concepts of programmatic risk (to cost and schedule) and operational risk (to life and property) must be carefully separated.

Requirements, especially safety requirements, for a human-rated launch vehicle must be specific, unambiguous, and verifiable. New programs must follow NASA's Human Rating Requirements (NPG 8705), protect those requirements from unnecessary "tailoring," weakening, and abandonment, and ensure that they are met.

Thorough, objective trade studies must be done to identify the design that best meets the requirements. Choices of technology and architecture should be guided by flight safety over cost, schedule, or any other priority.

New programs should choose conservative, simple designs, which are usually safer. They should adopt proven design standards and analytical approaches. Designs should preserve healthy margins and factors of safety, and employ redundancy in critical systems. Human rating should be designed in, not appended on. Well-understood, high-quality, high-reliability materials, components, and architectures should be selected. Hardware and software should be designed to degrade gracefully rather than fail catastrophically. The system must provide human insight into subsystems and allow human intervention during failures. Future improvements and supplementary backup systems must not be assumed to adequately substitute for a good basic design.

The Astronaut Office recommends that new human-rated launch vehicle programs follow guidelines, such as those given in the CAIB Report and NASA's Human Rating Requirements (NPG 8705), for safety-conscious management, requirements definition, concept development, and design selection.

IV. Predicted Reliability of New Designs

History has shown that rocket developers may exaggerate the merits of their systems. An early claim for the Space Shuttle's probability of crew survival was 0.99999, thousands of times safer than later demonstrated.[6] Because safety is the most important consideration for human-rated space vehicles, predicted reliability must be quantitatively understood at all stages of design.

A long record of successful flights is the best way to demonstrate flight safety. When a new system lacks enough flight history to support reliability claims, test results are the next best choice. During early development there is no hardware to test, so reliability must be predicted using state-of-the-art modeling techniques such as probabilistic risk assessment. Unfortunately, predicted reliability figures can be suspect, even if they are produced using modern, standardized techniques. The system developer owns the proprietary data upon which the models are based and these data are rarely shared for independent verification. Complex reliability models contain numerous parameters that are uncertain or subject to interpretation. (Models of this kind are notorious for being able to produce any answer the modeler wants to obtain.) Some reliability models treat only component failures, neglecting human errors in processing and operations. Finally, most reliability models treat only known modes of failure and may miss significant risks from unforeseen causes, especially unintended interactions between parts of a complex system (such as foam from the Shuttle's external tank striking the wing leading edge).

Greater confidence in predicted reliability numbers can be realized in several ways. One is to specify standard modeling methods for producing them. Another is to validate them through independent third-party verification using separately developed models. It may also be possible to truth-test reliability models against comparable existing systems with more precisely known reliability. Many models can be made more realistic by expanding them to include human errors in processing and operations as well as the possibility of unanticipated failure modes. Verification of this kind is difficult to obtain, but the powerful influence of model reliability estimates in determining the ultimate safety of the design (and hence the ultimate success of the program) demands thorough validation of the models and their results.

The Astronaut Office recommends that NASA specify and maintain a set of formal, standardized, complete methods and processes to be used in predicting the reliability of human-rated spacecraft, and identify or create an independent body to verify those analyses.

V. Verifying Flight Safety through Testing and Operations

Once hardware is built, its reliability can be accurately assessed, first through testing and later during operations. Because testing will expose the vulnerabilities in a system more accurately and more realistically than analysis, vigorous testing to qualify all levels of the system, including individual and integrated components, on the ground and in flight is essential. Flight testing should progressively expand the envelope, following proven aviation practices. Test flights should identify the system's weakest parts and exercise them most strenuously. The flight test program must demonstrate that the system's reliability meets the requirements, either through the sheer number of tests, through proving a safe envelope much larger than expected during operations, through validation of system models, or through a combination of all three.

The formal test program for a new commercial or military airplane involves hundreds of test flights. The large number of tests yields complete, precise understanding of the hardware and its performance. Such a comprehensive test program for a new spacecraft is likely to be prohibitively expensive. It is therefore expected that the next new human-rated spacecraft will be much less well understood than the next new military airplane when it goes into operation. Accordingly, even after completion of a formal test program, the spacecraft should still be operated as though it were an experimental vehicle. Operational practices associated with this paradigm include collection, archiving, and timely analysis of data on the health and performance of all systems. All anomalies should be recorded, tracked, and aggressively investigated. Unresolved anomalies should be considered constraints to flight. The system's reliability estimates and their underlying models must be continuously refined to reflect the vehicle's actual performance. An ancillary advantage of such an operational paradigm is that it will formally identify and capture ideas that will be useful in further improving the safety of current and future launch vehicles.

The Astronaut Office recommends that the test program for the next human-rated launch system demonstrate its reliability through vigorous ground and flight testing of components and systems. The value of each test should be leveraged by proving a safe envelope larger than that expected during operations and by using flight data to validate system reliability models. After completion of the formal test program, the vigilance applied during testing to data gathering, analysis, and flight constraints should continue to be applied during operations. Reliability should be continuously reassessed.

VI. Improving Ascent Safety with Abort and Escape Systems

The current benchmark for ascent reliability is the Space Shuttle's success rate of 0.991. Existing commercial rockets have lower success rates.[1] Given the low reliability of even the safest existing rockets, meeting the Astronaut Office's goal of an order-of-magnitude reduction in the risk of space flight will require making the risk of losing the <u>crew</u> much smaller than the risk of losing the <u>booster</u>. This can be achieved by adding abort and escape systems. The "Astronaut Office Position on Crew Survivability During Ascent and Entry"[5] defines an "abort" as a failure case where the crew stays in the part of the spacecraft normally designed to carry them during entry, as with an Apollo-style tractor rocket. "Escape" means that the crew leaves the crew compartment after the failure, as with an escape pod, ejection seats, or bailout capability. A successful abort or escape is one in which the crew survives abort or escape initiation, separation from the booster, descent and landing, awaiting rescue forces, and being securely recovered by those forces. All elements involved in abort or escape flight, landing, post-landing survival, and rescue efforts are considered part of the abort or escape system. Portions of the flight trajectory where abort and escape are impossible are called "black zones." Because the overall safety of the system depends so strongly on the abort or escape system, black zones greatly increase overall flight risk. They should therefore be minimized to the fullest extent possible. The safest design will include a "full envelope" abort or escape system, which provides the crew with a secondary way to survive vehicle failures at all points in the flight profile.

Abort and escape systems must operate very quickly and precisely, may need to withstand the detonation of hundreds of tons of explosive propellants in close proximity, must perform across a wide and never fully understood range of conditions, and may drop the crew compartment onto inhospitable locations on the Earth's surface where the crew might wait days to be rescued. The reliability of an abort or escape system must include its ability to save the crew from all credible failures at all times during ascent, and its ability to protect them after separation from the rocket until recovery by rescue forces.

Abort and escape systems can never be perfectly reliable. Historically, about 13% of rocket accidents have involved catastrophic stack failures occurring with so little warning that notional abort or escape systems likely could not have saved a crew on board.[1] Considering the challenges of separation alone, abort or escape system reliability figures higher than about 0.87 may be difficult to achieve without specifically designing the booster to fail only in benign ways. Even if separation from the failing booster is successful, abort descents, landings, and rescue scenarios are more difficult to survive than their nominal counterparts, implying an overall abort or escape system reliability even lower than 0.87. Because of the abort or escape system's vital role in protecting the lives of the crew, its reliability estimates must be comprehensive and realistic during the design phase, and supported by rigorous flight-testing after hardware exists.

The table below shows how the rate of fatal accidents depends on the reliabilities of the booster and the abort or escape system. To clearly illustrate the effect of both parameters, we convert ordinary reliability figures (e.g., 0.999) to expected numbers of fatal accidents per 1,000 launches. Presented in this format, the Space Shuttle's 0.991 ascent success rate becomes 9 fatal accidents per 1,000 launches, and the Astronaut Office safety target of 0.999 is one fatal accident per 1,000 launches. In the table, green denotes combinations of booster and abort system reliabilities that meet that target. Systems with two or fewer fatal accidents per 1,000 launches are shown in yellow.

Table 1. Fatal ascent accidents per 1,000 launches, for different values of booster and abort or escape system reliability.

Booster Reliability	Abort or Escape System Reliability 0.800	0.850	0.900	0.950
0.995	1.0	0.75	0.5	0.25
0.990	2.0	1.5	1.0	0.5
0.980	4.0	3.0	2.0	1.0
0.970	6.0	4.5	3.0	1.5
0.960	8.0	6.0	4.0	2.0
0.950	10.0	7.5	5.0	2.5

The table shows that if the abort or escape system has a reliability of 0.900 (chosen as a reasonable upper limit, following the discussion above and presuming a booster designed not to fail catastrophically, so that the abort or escape system reliability can exceed 0.87), the Astronaut Office safety target of 1 fatal accident per 1,000 launches can be reached only by selecting a booster with a reliability of 0.990 or better. Existing commercial rockets have demonstrated reliabilities near 0.950 with 95% confidence.[1] The Space Shuttle, if viewed solely as a launch vehicle, has a high success rate of 0.991, but applying the standard 95% confidence level puts its demonstrated reliability near 0.960. A new booster design that avoids complex, fragile, and unproven technologies and architectures while embracing the more extensive testing, design margins, process control, instrumentation, operator intervention, and fault tolerance characteristic of current human-rated flight hardware might achieve or exceed 0.990 reliability with high confidence.

The Astronaut Office believes that the next human-rated spacecraft must include a robust full-envelope abort or escape system. The safety of the overall system depends on the reliability of both the booster and the abort or escape system. As with the rocket itself, the abort or escape system reliability must be proven through flight testing.

VII. Launching Humans on Atlas V and Delta IV Boosters

The possibility of using the current Atlas V and Delta IV rockets to launch a new, piloted spacecraft has led the Astronaut Office to look closely at the crew safety implications of this option.

- According to the OSP-ELV Human Flight Safety Certification Study Team Report,[1] the Atlas V and Delta IV rockets do not meet many of the NASA safety standards specified or referenced in NPG 8705, the Human Rating Requirements. Major changes needed to bring the vehicles into compliance would include at least: adding failure tolerance for critical systems, redesigning for greater structural safety factors (human-rated spacecraft use 1.4; Atlas V and Delta IV rockets use 1.25), adding fault detection and isolation functions, making the range destruct philosophy compatible with maximum crew survivability, wiring for insight and intervention by the crew and ground control, performing the detailed risk analyses needed for human rating, supplementing process controls in all phases of production, and flight testing to human rating standards.

- The Atlas V and Delta IV boosters were built to be cost-effective for their manufacturers, insurers, and customers, considering the value of the non-human payloads they were designed to carry. Although cost-effectiveness includes reliability considerations, safety is not the prime driver for satellite launches. The expense of human rating these existing rockets by adding design margins, redundancy, instrumentation, process control, command capability, and testing, might make them uneconomical for their original mission and could potentially be as costly as building a new human-rated booster.

- The reliability of Atlas V and Delta IV rockets is not precisely known because they are too new. Given insufficient flight data, one method for predicting reliability is to assume that a new system is about as reliable as a similar, existing system. The OSP-ELV Human Flight Safety Certification Study Team[1] used the flight record of Atlas, Delta, and Titan rockets developed under U.S. Government contracts and launched since 1990 to predict the reliability of the Atlas V and Delta IV. These rockets have been launched 236 times and reached safe orbits 230 times. The resulting reliability estimate is 0.950 or better with 95% confidence. The boosters' potentially low reliability would place excessive burden on abort mechanisms to save the crew. The abort or escape system would need a reliability near 0.980 for the complete launch system to meet the Astronaut Office crew survivability target. Proposed abort and escape systems were judged to be incapable of rescuing the crew from stack detonations occurring with little or no warning.[1] These failures occur often enough to prevent even a high-reliability abort or escape system from meeting its safety requirement.[1]

- Atlas V and Delta IV boosters fly to orbit on highly lofted trajectories because of second-stage performance limitations and range destruct line-of-sight requirements. If a piloted spacecraft had to abort near the apex of such a trajectory, it would hit the atmosphere at a high speed and a steep angle. The resulting heat and acceleration loads on the crew compartment would be severe and possibly not survivable.[7]

In summary, the Atlas V and Delta IV rockets should be measured against a set of concrete, specific, verifiable requirements for carrying humans before being selected for that purpose. A safer launch option might be identified by objectively comparing the advantages and drawbacks of a range of existing, modified, and new launch systems relative to those requirements.

VIII. Summary and Conclusion

If we wish to send explorers into space on increasingly ambitious missions, we must first solve the problem of getting humans into orbit more safely than is possible with our current launch systems.

The Astronaut Office believes that an order-of-magnitude reduction in the risk of loss of human life during ascent, compared to the Space Shuttle, is both achievable with current technology and consistent with NASA's focus on steadily improving rocket reliability, and should therefore represent a minimum safety benchmark for future systems. This corresponds to a predicted ascent reliability of at least 0.999. To ensure that a new system will achieve or surpass its safety requirement, it should be designed and tested to do so with a statistical confidence level of 95%.

Tough safety requirements can be met in part by adopting the best practices for the management, design, test, and operation of risky technology as given in the CAIB Report, in NASA's Human Rating Requirements (NPG 8705), and in commercial and military aviation.

The burden of proving that a vehicle is safe falls on the mathematical models, tests, and operational history that measure the system's reliability. Accordingly, the Astronaut Office recommends that NASA specify and maintain a set of formal, standardized methods and processes to be used in predicting the reliability of human-rated spacecraft, and identify or create an independent body to verify those analyses. We further recommend that the test program for the next human-rated launch system demonstrate its reliability through vigorous ground and flight testing of components and systems. The value of each test should be leveraged by proving a safe envelope larger than that expected during operations and by using flight data to validate system reliability models. After completion of the formal test program, the vigilance applied during testing to data gathering, analysis, and flight constraints should continue to be applied during operations. Reliability should be continuously reassessed.

The Astronaut Office believes that the next human-rated spacecraft must include a robust full-envelope abort or escape system. The reliability of both the rocket and the abort or escape system are limited and must be proven through flight-testing.

It is our hope that NASA will adopt the principles outlined in this paper to design, build, test, and fly a new vehicle that is much safer than its existing counterparts. Such a vehicle will help ensure that our nation retains the capability for human access to space.

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SPACE NEWS

November 30, 2009

Don't Let U.S. Lose Leadership in Space

By Rep. Ralph Hall (R-Texas)

There is a lot at stake for the future of human spaceflight. Forty years ago America became the undisputed leader in space when we successfully landed on the Moon. This feat inspired a generation of scientists and engineers who helped solidify America's position as the world's leader in high-tech innovation. Today, America's space agency faces some difficult decisions. NASA will soon retire the Space Shuttle, but has yet to complete the next generation vehicle. The gap will result in reliance on Russia to ferry our astronauts to and from the International Space Station (ISS), a situation that raises a host of concerns.

Without our own vehicle to access the ISS, America risks losing its position of leadership in space. The ISS represents the culmination of the greatest engineering project perhaps in human history, and the U.S. has led in this effort. The gap in spaceflight capability *must* be minimized, and we must accelerate development of the follow-on system. However, before evaluating the best way to move forward, perhaps we should first reflect on how we've arrived in this position.

In the aftermath of the Columbia tragedy, America did some soul-searching. The Columbia Accident Investigation Board (CAIB) concluded that there was a "failure of national leadership" that contributed to the accident and to NASA's inability to finish earlier programs deemed as hoped-for replacements for the Space Shuttle. The CAIB encouraged Congress and the White House to clarify our goals in space. I was encouraged in early 2004 when the Administration unveiled the Vision for Space Exploration, giving the Space Agency clear direction and measurable goals. NASA was directed to complete the ISS and to develop a capability to fly beyond low Earth orbit, allowing us to return to the Moon and eventually pursue a "flexible path" of exploration through the solar system. Giving NASA a clearly defined destination and the clearly defined design requirements that go with it will help ensure long-term success.

The CAIB also acknowledged that human spaceflight is a risky endeavor and said that "the design of the system should give overriding priority to crew safety, rather than trade safety against other performance criteria, such as low cost and reusability." I couldn't agree more that crew safety must be a top priority when developing any new launch system.

After the Vision was announced, Congress held numerous hearings to review the Constellation program proposed by NASA, and in the end agreed with the goals and architecture of the plan. It is important to note that both the 2005 and 2008 NASA Authorization Acts reflect broad, bipartisan, bicameral support from Congress for the elements of that original vision. But unfortunately the funding necessary to fully achieve this vision, along with NASA's many other missions, has been inadequate. I have said many times before that for too long NASA has been asked to do too much, without the proper funding. This lack of funding has led us to where we are today.

Congress has a strong desire and need to minimize the gap. Independent American access to the ISS is a strategically important national imperative. The best way to achieve this is to accelerate development of the Orion Crew Exploration Vehicle and Ares 1 Crew Launch Vehicle. Significant progress has already been made in developing these capabilities, and to abandon that progress would be a step backward. In support of that position, last year Congress authorized an additional $1 billion above the President's FY 2009 NASA budget request to accelerate the development of the Constellation system.

Another proposal that some Members of Congress believe could help NASA during the gap is to foster a commercial cargo delivery service to the ISS. However, it is important to note that Congress did not endorse a commercial crew option as an appropriate solution for the U.S. to meet our responsibilities and commitments to our international partners. A commercial crew capability simply could not be properly evaluated and ready in time to safely fly our astronauts during the gap. The commercial crew demonstration initiatives in the NASA Authorization Act were not intended to supplant development of Ares 1 and Orion. As I said, astronaut safety must be the top priority. After the Space Shuttle is retired, NASA will still be required to provide crew rescue capabilities for ourselves and our international partners from the ISS. The Ares 1 launch vehicle and the Orion capsule are being designed with these goals in mind.

The Obama Administration should currently be putting the finishing touches on the fiscal year 2011 budget that will be submitted to Congress early next year. I urge the President to request adequate funds so that NASA can maintain its leadership role in space. Without this leadership it will be difficult for Congress to appropriate the necessary funding. We must be mindful of our federal budget and direct taxpayer dollars to priorities that generate the greatest return on our investment. Our space program has possibly contributed as much or more than any civilian government program to securing America's technological and economic leadership in the world. The plan Congress authorized is one worthy of a great nation.

Chairwoman GIFFORDS. Without objection.

Mr. HALL. And with that, I want to just say another word or so about Tom Stafford. He graduated from the U.S. Naval Academy ten years after Sam Rayburn came to my breakfast table to talk to my mother to tell her why he couldn't appoint me to the Naval Academy. They were in school together at Mayo College there. It is now Texas A&M at Commerce, but they were friends forever. She was part of the first team to ever get Sam Rayburn to run for office. She wanted him to appoint me to the Naval Academy. He said there are just four reasons and all four reasons are his grades. Later, Madam Chairman, that came home to me because they ran an article in the paper when I was running for reelection for judge one time that I had made four F's and a D one time and my dad had punished me for spending too much time on one subject. That wasn't very good. But Tom has also flown two Gemini missions. He is the first Gemini mission, and he piloted the first rendezvous in space. He is cited by the Guinness Book of World Records for the highest speed ever obtained by a man, or a woman, I am sure, 24,791 miles per hour during the reentry of Apollo 10. He was instrumental in our early space missions with the Russians. He logged over 507 hours in space and flew four different types of spacecrafts. He obtained the rank of three-star general and he served as a defense advisor to one of the great Presidents of the century, President Ronald Reagan. Tom and you other five gentlemen, we thank all of you for what you are doing and your presence here today.

I yield back. Thank you, Madam Chairman.

[The prepared statement of Mr. Hall follows:]

PREPARED STATEMENT OF REPRESENTATIVE RALPH M. HALL

Madame Chair I want to thank you for recognizing me to make a statement, and for holding today's hearing on ensuring the safety of human space flight in future space transportation systems. It is one of the topics I am most passionate about. Safety of our crews simply *must* be at the heart of everything NASA does in space.

I also want to sincerely thank all of today's witnesses for taking the time and effort to share their unique and valuable wisdom and expertise with us. I especially want to welcome General Tom Stafford. Tom is a good friend and a real national hero. I have relied on Tom's advice for many years, most recently when he chaired the Stafford-Covey Return to Flight Task Group that was established to ensure the Columbia Accident Investigation Board's recommendations were carried out.

We have a lot of very important issues to cover today so I will be brief.

The Columbia accident board gave NASA many safety recommendations and principles to follow in the design of future launch vehicles. In May 2004, after carefully reviewing the findings, the Astronaut office published their position on the safety of future launch systems. One recommendation was to include a crew escape system as part of any new launch vehicles. In the NASA Authorization Bill of 2005, I ensured that such a system was part of NASA's plans for the next human exploration vehicle, and I will continue to insist that this remains the case.

Much of what I would say today is in my editorial piece in Monday's edition of *Space News*. Madame Chair I'd like to ask unanimous consent to include a copy of the May 4, 2004 Astronaut Office Position on Future Launch System Safety; and a copy of my November 30, 2009 *Space News* editorial into the record.

With that, I look forward to a very productive hearing and yield back my time.

Chairwoman GIFFORDS. Thank you, Mr. Hall.

If there are other members who wish to submit additional opening statements, your statements will be added to the record at this point.

Mr. OLSON. Madam Chairwoman?

Chairwoman GIFFORDS. Yes.

Mr. OLSON. May I make an opening statement?

Chairwoman GIFFORDS. Sure.

Mr. OLSON. Thank you very much. I appreciate that, and I know part of this is my fault for getting the ranking member in here.

Madam Chairwoman, thank you for calling this morning's hearing on a topic of paramount importance to the future of our human spaceflight program. The issue of safety is really the starting point from which all discussions about the course and purpose of our Nation's human spaceflight program should begin. I am certain we would have a line of people out the door to test-drive the new rocket. That pioneering spirit is in the fabric of our Nation, but we must not take it for granted, not cheapen it by failing to provide the direction or performance, performing the diligence necessary to ensure the astronauts' safety.

I would like to thank our witnesses for their appearance before the Subcommittee today. I recognize that each of you has spent considerable time and effort preparing for this hearing and in some cases traveling long, long distances to be here, and we are not going to calculate General Stafford's distance that he has traveled because he has got a big advantage over the rest of us. But please know that the Subcommittee appreciates your efforts as well as the wisdom and experience you bring and that we will refer to your guidance in the coming months and years ahead as the Committee goes forward.

NASA is facing a transition away from the space shuttle to the Constellation program, a program that is in the midst of testing and design, desperately needs more funds, and thank you, Mr. Hanley, for all you have done for the Constellation program. But there is a theme across our entire spaceflight program, human spaceflight program. An increase in resources would enhance the abilities and capabilities of the commercial sector to allow their increased participation as well. I fully support all of the current endeavors including commercial cargo, but sadly, from my position, fully supporting and fully funding are not synonymous. I truly wish they were.

Safety is and must be on the minds of the men and women of NASA all the time. We have astronauts orbiting in the ISS right now and each shuttle flight carries with it the extra increment of risk that an accident could end NASA as we know it.

I would like in my brief time to focus on an area of concern to me that is just as critical as design standards, human ratings requirements, airworthiness, to name a few, and that is the issue of culture. Culture is difficult to define. I know that. But it is something that the Columbia Accident Investigation Board spent a great deal of time on. It found that, and this is a quote, "The NASA organizational culture had as much to do with this accident as the foam." The Augustine report cites that, another quote, "Significant space achievements require continuity of support over many years. One way to assure that no successes are achieved is to continually introduce change."

It must not be lost on this committee that the increased participation of commercial providers will necessitate a change in business as usual at NASA. We cannot take that lightly. Changing the way a bureaucracy operates is not easy. In many cases, it is not advisable, and frustratingly, in most cases, not achievable, but make no mistake, I am not for letting the status quo dictate the way our government runs. I am just stating that in this case, a change like this brings challenges and risk that we must not overlook.

The agency faces limited budgets, massive contractor layoffs and retirement of the signature program and perhaps a new way of doing things. Again, a new way of doing things is not inherently bad. I am not saying that. I am just saying it would bring forth challenges to a workforce and systems and processes that are every bit as difficult as designing rockets.

I do not believe the CAIB report is a historical artifact but a guiding document. The Constellation program was designed with the CAIB freshly in mind, and we must keep that report fresh in ours as time goes on.

The challenge of a lack of funding permeates every discussion we have about NASA but not a distant second is a lack of commitment to a defined program. We have a program before us. It is time we committed to it with our actions and the funding necessary to see it through. In my mind, the cost of not doing so far exceeds the amount needed to complete the task. We are a Nation founded by great explorers who were willing to take great risks. Great success is achieved out of the willingness to make great sacrifice. However, as a Nation, especially at taxpayer expense, we must be diligent in making sure that the promised success is worth the promised sacrifice.

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 on a topic of paramount importance to the future of our human space flight program. The issue of safety really is the starting point from which all discussions about the course and purpose of our nation's human space flight program should begin.

I am certain we would have a line of people out the door (and behind me, by the way) to test ride a new rocket. That pioneering spirit is in the fabric of our nation, but we must not take it for granted, nor cheapen it by failing to provide the direction or performing the diligence necessary to ensure their safety.

I'd like to thank our witnesses for their appearance today before this subcommittee. I recognize that each of you has spent considerable time and effort preparing for this hearing, and in some cases traveling considerable distance (although we won't calculate all of Gen. Stafford's career miles) 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.

NASA is facing the transition away from the space shuttle and to the Constellation program, a program that although is in the midst of testing and design, desperately needs more funds. But that is a theme across our entire human space flight program. An increase in resources would enhance the abilities and capabilities of the commercial sector to allow their increased participation in space as well. I fully support all of the current endeavors, including commercial cargo, but sadly from my position, fully supporting and fully funding are not synonymous. I truly wish they were.

Safety is and must be on the minds of the men and women at NASA all the time. We have astronauts orbiting in the ISS right now, and each shuttle flight carries with it the extra increment of risk that an accident could end NASA as we know it.

I would like in my brief time to focus on an area of concern that to me is just as critical as design standards, human-ratings requirements, and airworthiness, to name a few (and not making light of any of them) and that is the issue of culture.

Culture is difficult to define I know, but it is something that the Columbia Accident Investigation Board spent a great deal of time on. It found that "the NASA organizational culture had as much to do with this accident as the foam."

The Augustine report cites that "significant space achievements require continuity of support over many years. One way to assure that no successes are achieved is to continually introduce change." It must not be lost on this committee that the increased participation of commercial providers will necessitate a change in business as usual at NASA. We cannot take that lightly. Changing the way a bureaucracy operates is not easy, in many cases not advisable, and frustratingly, in most cases, not achievable. Make no mistake, I am not for letting the status quo dictate the way our government runs, I am just stating that in this case a change like this brings challenges, and risks, that we must not overlook.

The agency faces limited budgets, massive contractor layoffs, the retirement of a signature program, and perhaps a new way of doing things. Again, a new way of doing things is not inherently bad, I am not saying that, I'm just saying that it will bring forth challenges to a workforce and to systems and processes that are every bit as difficult as designing rockets.

I do not believe the CAIB report is a historical artifact, but a guiding document. The Constellation program was designed with CAIB freshly in mind, and we must keep that report fresh in ours as time goes on.

The challenge of a lack of funding permeates every discussion we have about NASA. But a not distant second is the lack of a commitment to a defined program. We have a program before us; it is time we committed to it with our actions and the funding necessary to see it through. In my mind, the cost of not doing so far exceeds the amount needed to complete the task.

We are a nation founded by explorers who were willing to take risks. Great success is achieved out of the willingness to make great sacrifice. However, as a nation, especially at taxpayer expense, we must be diligent in making sure that the promised success is worth the possible sacrifice.

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

Mr. HALL. Will the gentleman yield to me just one minute before he yields back his time?

Mr. OLSON. Yes, sir. Yield back to the ranking member.

Mr. HALL. Madam Chairperson, we have in the audience a longtime staffer and part of the bedrock of the NASA program and the bedrock of this Committee, Tom Tate. Tom, we are always glad to have you back here and thanks for the many years you have spent back on this side of the desk.

Thank you, Madam Chairman. I yield back.

Chairwoman GIFFORDS. Thank you.

Because we anticipate votes probably occurring in about 45 minutes, I am going to ask if other members have additional opening statements that we submit them for the record at this point.

We do have a distinguished set of panelists today. I would like to introduce them briefly. Mr. Bryan O'Connor is here. He is a veteran of two space shuttle missions and is currently the Chief of Safety and Mission Assurance at NASA. He will be discussing NASA's processes and plans for resolving safety and human rating issues. Next we will hear from Mr. Jeff Hanley, who is Program Manager for the Constellation program at NASA. He will be discussing the steps taken by the Constellation program to maximize crew safety in its Ares-Orion System. We will also hear from Mr. John C. Marshall, who is a Council Member on NASA's Aerospace Safety Advisory Panel. He will provide the perspectives of the agency's outside safety advisory board. Welcome. Also, we will hear from Mr. Bretton Alexander, who is currently the President of the Commercial Spaceflight Federation. He will provide the commercial industry's perspectives and plans for addressing crew safety issues. Welcome. Dr. Joseph Fragola is Vice President of Valador Incorporated. He has more than 40 years experience in risk analysis in the aerospace and nuclear industries and will provide his perspectives on the issues involved in ensuring the safety of both government and non-government crew space transportation systems, a true expert. Welcome, Dr. Fragola. And of course, Lt. Gen. Tom Stafford, who has been introduced a couple times already. We are just very, very delighted that you are here.

As our witnesses should know, you will each have five minutes for your spoken testimony. Your written testimony will be included in the record for the hearing, and when you have completed your spoken testimony, we will begin with questions, and each member will have five minutes to question the panel, and we would like to begin this morning with Mr. O'Connor.

STATEMENT OF BRYAN O'CONNOR, CHIEF OF SAFETY AND MISSION ASSURANCE, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. O'CONNOR. Thank you, Chairwoman Giffords, members of the Subcommittee. I appreciate the opportunity to appear here today to discuss how NASA works to ensure the safety of human spaceflight. In your letter inviting me to testify at today's hearing, you asked that I address a number of questions related to the Office of Safety and Mission Assurance at NASA and how we work with safety of human spaceflight. My statement will address those questions and provide additional context.

The Office of Safety and Mission Assurance provides policy direction, functional oversight and assessment for all agency safety reliability and quality engineering activities. We are responsible for the agency's safety and mission assurance requirements and standards and we serve as principal advisor to the Administrator on matters pertaining to human spaceflight safety and mission success.

In the past several years, my organization has sponsored several initiatives to take advantage of our lessons learned from the past 50 years of human spaceflight. Included are increased emphasis on the qualifications and credibility of our professional workforce, formal technical authority for associated safety and mission assurance requirements as well as the authority to determine safety risk acceptability for designs and for operations including human spaceflight launch, increased emphasis on safety culture throughout the human spaceflight programs. This includes more open communications including encouragement for dissenting opinions, clear appeal paths all the way to the Administrator as necessary for safety dissenting opinion, and something we started recently called the "Yes If" initiative. It is an incentive that promotes the ideal that credible and capable safety and mission assurance professionals don't simply just know the rules but they understand the rationale behind those rules to the point that they can help the designer and the operator with alternative approaches consistent with safety and mission success, improvements in critical software, independent validation and verification and improvements in our knowledge management systems. A significant portion of these activities as well as improved audits, assessment and mishap investigation procedures and capabilities in the agency are primarily managed at the new NASA Safety Center, which we established two years ago in Cleveland near the Glenn Research Center.

As I mentioned, much of our current thinking comes from hard lessons learned from the past. The Columbia Accident Investigation Board documented for us once again the inherent risk of human spaceflight, noting that "the laws of physics make it extraordinarily difficult to reach earth orbit and return safely." To justify that risk the CAIB called for "a national mandate providing NASA a compelling mission requiring human presence in space." It also recommended that design of the shuttle replacement should give overriding priority to crew safety rather than to trade safety against other performance criteria such as low cost and reusability or against advanced space operations capabilities other than crew transfer. The X–15 incidents, the Apollo fire, the *Challenger*, the *Columbia* accidents have caused us to insist on clear lines of accountability in what we do with strong checks and balances, capable systems integration and a strong safety culture with open communications in all directions. We treat every crewed spaceflight like an engineering test flight, retaining adequate program resources to thoroughly prepare for each flight and to analyze and resolve ground and flight anomalies. Finally, we emphasize crew escape and emergency systems to improve crew survivability during anticipated or unanticipated flight contingencies.

We have also learned an awful lot working with our Russian counterparts beginning in Apollo-Soyuz and continuing with Shuttle-Mir and the International Space Station about the challenges of spaceflight and safety of human spaceflight. For example, we note in the Soyuz design the robust reliability and failure tolerance features. The systems for unknown contingencies are treated with capable, highly capable abort, escape and emergency systems.

On the matter of crew egress and escape and abort, the Columbia Crew Survival Investigation Report prepared by NASA Spacecraft Crew Survival Integrated Investigation Team released last December is a comprehensive study of crew safety equipment and procedures used during the Space Shuttle *Columbia* accident. We have made this report available to the Constellation program as well as to industry for use and guidance in their design for survivability.

Finally, as we review the options presented by the Augustine panel, we are considering how best to address their suggested commercial crew transportation options. We are using fiscal year 2009 Recovery Act funds to supplement or to support activities related to technologies that enable commercial human spaceflight capabilities. We are also investing Recovery Act funds to begin development of a more concise set of human rating technical requirements that might apply to non-NASA developers and we are looking at appropriate oversight and insight approaches to be used for such a venture.

In closing, the Office of Safety and Mission Assurance plays a significant role in assuring safety of human spaceflight. Chairwoman Giffords, I would be happy to respond to any questions you or other members have on this matter.

[The prepared statement of Mr. O'Connor follows:]

PREPARED STATEMENT OF BRYAN O'CONNOR

Chairwoman Giffords and other Members of the Subcommittee, thank you for the opportunity to appear today to discuss how NASA works to ensure the safety of human spaceflight. In your letter inviting me to testify at today's hearing, you asked that I address a number of questions related to the Office of Safety and Mission Assurance and the safety of human spaceflight at NASA. My statement will address those questions, and provide additional context.

The Role of OSMA in Ensuring Human Spaceflight Safety

The NASA Office of Safety and Mission Assurance provides policy direction, functional oversight, and assessment for all Agency safety, reliability, maintainability, and quality engineering and assurance activities and serves as a principal advisory resource for the Administrator and other senior officials on matters pertaining to human spaceflight safety and mission success. As Chief of the Office of Safety and Mission Assurance, I report directly to the Administrator. OSMA supports the activities of—but is organizationally separate from—the human spaceflight Mission Directorates and the Office of the Chief Engineer, thus providing the Administrator an independent view of the safety and effectiveness of human spaceflight designs, flight test and mission operations in addition to all other mission roles of the Agency.

Specifically, the Office of Safety and Mission Assurance:

- Develops strategies, policies, technical requirements, standards, and guidelines for system safety, reliability, maintainability, and quality engineering and assurance;

- Establishes the applicable set of Safety and Mission Assurance (SMA) requirements for all human spaceflight programs, and, through delegated technical authority, formally approves or disapproves waivers, deviations and/or exceptions to same;
- Verifies the effectiveness of safety and mission assurance requirements, activities, and processes, and updates, cancels or changes them as time, technology and/or circumstances dictate;
- Advises NASA leadership on significant safety and mission assurance issues, including investigation of human spaceflight-related mishaps and close calls, and provides guidance for corrective actions stemming from those investigations as well as corrective actions related to ground and flight test anomalies;
- Performs broad-reaching independent assessments of human spaceflight-related activities, including formal Independent Validation and Verification (IV&V) of flight and ground software critical to flight crew safety;
- Oversees and assesses the technical excellence of safety and mission assurance tools, techniques, and practices throughout the human spaceflight program life cycle;
- Provides knowledge management and training in safety and mission assurance disciplines to the assigned workforce; and,
- Assures that adequate levels of both programmatic and Center institutional resources are applied to safety and mission assurance functions.

NASA Human Spaceflight Safety Initiatives

In the past several years, OSMA has sponsored several initiatives with the intent of enhancing the safety of human spaceflight. OSMA has increased its emphasis on the qualification and credibility of safety and mission assurance professionals by working with the Center Directors to assign some of their best and brightest employees to safety and mission assurance positions. We have also established a new Technical Excellence Program with a four-tier training and qualification system for all safety and mission assurance professionals across the Agency. Additionally, safety and mission assurance professionals assigned to human spaceflight programs now have formal technical authority for associated safety and mission assurance requirements as well as the authority to determine safety risk acceptability for designs and/or operations, including human spaceflight launch.

Another initiative is an increased emphasis on safety culture throughout the human spaceflight programs. This includes more open communications, including encouragement for dissenting opinions; clear appeal paths to the Administrator for safety dissenting opinions; and the "*Yes if*" initiative, an incentive that promotes the ideal that credible and capable safety and mission assurance professionals not simply know the rules, but understand their rationale to the point that they can help the design or operations team with alternative approaches consistent with safety and mission success.

OSMA has also made improvements in critical software IV&V by increasing the emphasis on validation of critical software requirements early in design. The IV&V team is also increasing the use of modeling and other systems engineering techniques to enhance their effectiveness in assessing the safety and utility of the critical software.

Improved knowledge management and requirements management tools and processes have also been put into place. This includes dedicated knowledge capture, archiving and dissemination activities, as well as better tools for tracking, updating, and rationalizing the more than 3,000 NASA technical and operational SMA requirements (many of which apply to human spaceflight). These activities, as well as improved audit, assessment and mishap investigation procedures and capabilities, are all primarily managed at the NASA Safety Center located near the Glenn Research Center.

Finally, OSMA has increased the amount of mentoring, training and technical assistance provided by our Headquarters SMA experts to the human spaceflight programs and their host Center SMA and engineering organizations.

Incorporating Lessons Learned into Agency Standards and Procedures

The Columbia Accident Investigation Board (CAIB) documented for us once again the inherent risk of human spaceflight, noting that "the laws of physics make it extraordinarily difficult to reach earth orbit and return safely." To justify the risk, the CAIB called for "a national mandate providing NASA a compelling mission requiring human presence in space." The Board also recommended that " the design of the Shuttle replacement] should give overriding priority to crew safety, rather than trade safety against other performance criteria, such as low cost and reusability, or against advanced space operation capabilities other than crew transfer."

The many CAIB recommendations dealing with root causal factors, as well as NASA's own Return to Flight assessments, pointed to several important lessons including, but not limited to, those outlined below. These recommendations and lessons indicate that NASA should:

- Maintain clear lines of accountability including strong checks and balances between program/project managers and their assigned independent technical authorities.
- Organize for a strong program-level systems integration function for complex, multi-element human spaceflight programs.
- Infuse the organization with a strong safety culture with open communications in all directions, encouragement of alternate opinions, and formal appeal paths for dissent.
- Treat every crewed space flight like an engineering test flight, and retain adequate program resources to thoroughly prepare for each flight and analyze and resolve ground and flight anomalies.
- Emphasize crew escape, abort and emergency systems and procedures to improve crew survivability during anticipated or unanticipated flight contingencies.

In the early 1990s NASA engaged in a joint U.S.-Russian project called Shuttle-Mir, picking up where the Apollo-Soyuz Test Project had left off in 1975. In preparation for the joint activity, NASA technical experts, including senior safety engineers, spent a significant amount of time over a three-year period talking with Apollo-Soyuz veterans, visiting with current Russian counterparts, and reviewing the long history of Soyuz, Salyut, and Mir operations in an effort to understand the Russian approach to human spaceflight safety. The two governments also established a high-level, joint technical oversight body (the Stafford-Utkin, now Stafford-Anfimov, Commission) in January 1995 to independently review Soyuz readiness for flight and to report its findings directly to the heads of agencies. In March 1995, Norm Thagard became the first U.S. astronaut to launch on the Soyuz. He and the other five astronauts who spent time on Mir used the Shuttle for subsequent transportation, but they all received training in Soyuz as their primary escape system.

Following on the success of the Shuttle-Mir program, NASA and the Russian Federal Space Agency (Roscosmos) agreed to create a joint space station in 1993. The International Space Station (ISS) Intergovernmental Agreement and Memorandum of Understanding (the final version of which was signed in 1998) recognized the Russian government's responsibility for crewmember safety for their elements, including Soyuz. The next American to launch on Soyuz was Bill Shepherd, the Commander of the first ISS increment in October 2000. Like Thagard, Shepherd returned to Earth on Shuttle, and like the Mir astronauts, he was trained on the Soyuz spacecraft. Since then, 14 different NASA astronauts have flown on Soyuz, bringing the total NASA astronaut trips to 14 up, and 13 down, several of which were made during the post-Columbia Return-to-Flight timeframe. Canadian and European partner astronauts have flown to and from ISS on Soyuz, and the next Soyuz will carry a Japanese partner astronaut. As we speak, Soyuz is the primary mode of transportation to and from the ISS for all ISS crewmembers.

NASA's Russian partner engineers and managers have been open with their designs, operations, system anomalies, and close calls; however, there have been occasions when, for various reasons, they have restricted technical information transfer to our engineers. On these occasions, perseverance by our technical staff on the ground and dependence on the Russians' proven engineering and operational savvy that spans more than 40 years of human spaceflight, have resulted in sufficient confidence in their systems and operations (approximately 96 percent mission success rate, and 98 percent crew safety record for all versions since 1967), and mutual trust initiated during the ApolloSoyuz program, and reinforced most recently with over 15 years of joint space station operations. Some of the many human spaceflight safety lessons from NASA's joint work with the Russians on Soyuz, Mir, and ISS include:

- The Russian design philosophy depends heavily upon reliability in addition to adherence to a strong design heritage (robust systems and failure tolerance, often using dissimilar redundancy), but they are big believers in abort, escape, and emergency systems for known or unknown contingencies that are not covered by reliability alone.

- The Russian design philosophy also rests heavily on testing. During the Soyuz update from the TM (modified transport) to TMA (TM anthropometric) version (enlarged in the 1990's to accommodate larger astronauts), they performed multiple tests, including drop tests, to ensure that the design was equivalent, or superior, to previous versions. This testing is often carried to conditions beyond the nominal expected environments. As Roscosmos prepares to upgrade the control computer system on the Soyuz, they are first installing and testing this upgrade in the Progress cargo vehicles. In this way, they can flight test the system with less critical cargo before it is required to transport crew. This provides an additional rigorous test and helps to insure overall crew safety.
- The Russian development philosophy is based on evolutionary upgrades, keeping what works, and modifying or replacing what does not.
- The Russian design and operational organizations include reliability and quality engineering staffs, but they do not have an independent safety engineering staff like NASA does. That said, they include many of the same safety functions as NASA does as part of the other engineering disciplines, and they do provide one of their most experienced engineers as NASA's SMA counterpart.
- The Russian technical staff is very skilled and displays outstanding knowledge of the flight systems. With relatively low turnover, they also have excellent corporate memory, which helps them deal with any repeat problems.
- The Russians, unlike NASA, rely on automation and ground control for certain critical dynamic events like abort initiation, landing, proximity operations and docking.

Although NASA and Roscosmos have occasionally disagreed about relative risk levels for such things as orbital debris, battery hazards, etc., our experience to date shows us that they have no intention of putting crewmembers in known unsafe situations for the sake of expediency.

The Columbia Crew Survival Investigation Report, prepared by the NASA Spacecraft Crew Survival Integrated Investigation Team (SCSIIT) and released in December 2008, is a comprehensive study of crew safety, equipment and procedures used during the Space Shuttle Columbia accident. The report contains 29 specific findings, half of which apply to Space Shuttle and to NASA investigation procedures, and half to future designs. The Constellation Program has assessed the report's findings, incorporating several of them into the Orion design, and the Program plans to incorporate others as the design matures. The fundamental theme of the findings is that human spaceflight programs should include crew survivability in the system design, and that operational plans should provide for safe egress, abort and/or escape from contingency situations. This is a top level requirement in NASA's most recent human rating requirements policy contained in NASA Procedural Requirement (NPR) 8705.2B (May 6, 2008). The rationale comes from our three fatal human spaceflight accidents. It is not enough to design a human spaceflight system to be reliable. The Earth-to-orbit mission is about managing incredibly high-energy systems and environments, with very little room for error. When measured by number of flights, human spaceflight transportation is still relatively immature, and the designers and operators are continuously learning about the real risks involved with spaceflight activities. Thus, as the report highlights, and the human rating requirements mandate, there is a need to provide the crew with a fighting chance for survival if and when something goes wrong, anticipated or not.

The Constellation Program is using the SCSIIT report as a design guideline; and as the Program tailors its suggestions into Program requirements, we in OSMA are drafting a follow-on technical standard for use by future human spaceflight system developers. The design standard will provide cues for designers and will also make it clear that the addition of any systems to increase the survivability of the crew needs to consider both the system design and concept of operations. In the meantime, NASA has made the SCSIIT report available to the public, sending copies directly to all known commercial space companies. The SCS1IT has also given presentations about the associated lessons-learned to NASA Centers, as well as to the National Transportation Safety Board, Federal Aviation Administration, the Department of Defense, the Defense Contract Management Agency, and others totaling over 4000 people to date.

Safety and Commercial Spaceflight

NASA will require that any Earth-to-orbit and/or orbit-to-Earth system that carries NASA astronauts be human rated, thus ensuring that all of our stringent crew and launch safety requirements would be met before any NASA crew would be allowed to travel on a spaceflight vehicle. As part of that process, the Agency's Technical Authorities (Engineering, SMA and Health and Medical) will determine which of NASA's mandatory standards apply in designing, manufacturing and operating their system. OSMA and the Johnson Space Center SMA organization worked closely with the Constellation program for over six months in 2008 to establish and tailor the applicable SMA requirements for the Constellation Program. This was a very detailed and involved activity that reminded us that the job of validating the right set of requirements for a new crewed flight system is not a simple cookie-cutter or checklist task. Nor is it expected to be a one-time task. The requirements refining and tailoring process will continue as we learn more about the design, the environment and the operational concepts. NASA's Commercial Crew and Cargo Program Office has initiated an effort to determine and establish the requirements (both process and design) as well as any other standards that should apply to commercial partners when engaging in services for transporting astronauts.

Currently, NASA is working with two companies, Space Explorations Technologies Corporation (Space X) and Orbital Sciences Corporation (Orbital), as part of individual Commercial Orbital Transportation Services (COTS) projects designed to develop and demonstrate commercial cargo capabilities to and from low-Earth orbit. In doing so, NASA has agreed to pay both companies prenegotiated amounts when each company achieves pre-negotiated milestones outlined in Space Act Agreements, and OSMA is part of the review team assessing each company's progress toward meeting required milestones. Last year, NASA also issued contracts to both Space X and Orbital, for cargo delivery to the ISS under the Commercial Resupply Services (CRS) Program.

NASA is utilizing FY 2009 Recovery Act funds to support activities to stimulate efforts to develop and demonstrate technologies that enable commercial human spaceflight capabilities. NASA is also investing Recovery Act funds to begin development of a more concise set of NASA human rating technical requirements. These requirements would be applicable to NASA developed crew transportation systems as well as commercially-developed crew transportation systems for use by NASA. This task is being performed by a team comprised of representatives from NASA's human spaceflight programs, the Astronaut Office, and Agency technical authorities, including OSMA. We are also consulting with other Government partners such as the Federal Aviation Administration and with commercial stakeholders.

Conclusion

In closing, the Office of Safety and Mission Assurance plays a significant role in ensuring the safety of human spaceflight. By continually improving its workforce, communications, and processes, the Office of Safety and Mission Assurance is an organization of technical excellence that is well-equipped to support the Agency's human spaceflight safety efforts. By disseminating and incorporating into its standards and policies the many lessons learned throughout the history of human spaceflight, NASA is able to improve safety in its own future designs, and to facilitate safety in those that may be developed commercially.

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, Mr. O'Connor.

Mr. Hanley.

STATEMENT OF JEFF HANLEY, PROGRAM MANAGER, CONSTELLATION PROGRAM, EXPLORATION SYSTEMS MISSION DIRECTORATE, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. HANLEY. Good morning. Chairwoman Giffords and members of the Subcommittee, thank you for the opportunity to appear here today to discuss NASA's emphasis on the continuing effort to improve safety factors for our most valuable commodity, NASA's astronauts. Simply put, safety is a top priority of NASA's Constellation program.

My testimony today will outline how the Constellation program has sought to improve crew safety above that achieved in previous crewed spacecraft. This has been accomplished by incorporating safety into the Constellation design process from the very beginning, and in doing so, we are ensuring that the Constellation vehicles are being designed to account for future missions beyond low earth orbit as well as the less challenging requirements of our current Space Station missions.

However, before we delve too far into the Constellation program's risk-informed design process, I think it is first important that we take a look back where we came from. Many of you have touched on some of that foundation here this morning already. Following the loss of the Space Shuttle *Columbia*, NASA chartered the Columbia Accident Investigation Board to provide the agency with the guidelines for moving forward with our return to flight activities. Mr. O'Connor cited the finding in their report, and I won't repeat it here again, that informed our design efforts going forward from there. The crew office also put out a memo then in 2004 weighing in on the discussion about how the next generation human spaceflight system should be designed, stating that an order of magnitude reduction "in the risk of loss of human life during ascent compared to the space shuttle is both achievable with current technology and consistent with NASA's focus on steadily improving rocket reliability and should therefore represent a minimum safety benchmark for future systems." NASA's Exploration Systems Architecture Study of 2005 used this guidance in recommending that NASA select a single, solid first-stage concept that would later become known as the Ares I Crew Launch Vehicle.

Today, the Constellation program has a design goal of increasing astronaut safety 10-fold relative to shuttle missions and we believe that this goal is achievable for four key reasons. First, Constellation is utilizing a multifaceted design approach that remains unchanged since Apollo: design the system to be inherently as safe as we can make it, eliminate known risks and hazards where we find them and then add backup such as an abort system to mitigate the residual risk. In addition to leveraging systems with human-rated heritage such as the space shuttle solid rocket motor, NASA is utilizing improved computer modeling to help identify, reduce and eliminate hazards and risks where we find them.

Second, unlike the space shuttle, the Orion capsule will have a launch abort system. During Apollo, NASA had comparatively little experience and computational capability and the abort effectiveness of such a system was only estimated. Today we can use advanced simulation tools and computers to test within the computer so that NASA can conduct a more thorough analysis in addition to utilizing test flights.

Third, Constellation has chosen to tightly interweave design and safety team members into the design process. The team has actively worked with design engineers to provide expertise and feedback via various assessments and analyses throughout the design maturation process and that process is ongoing and continues.

And finally, Constellation has used the agency's active risk management approach that identifies technical challenges early in the design process and aggressively works solutions. Technical risks are identified by likelihood of occurrence and consequence, allowing designers to modify the emerging design to reduce or eliminate hazards.

Currently, the Constellation program is progressing through an active phase of hardware and software tests, and as tests are completed and data analyzed, our models will be updated, allowing us to improve safety and improve system performance. At the same time, we are investing heavily in risk-reduction hardware and activities that will help better calibrate and refine our models and simulations data that is essential to incorporate as early as possible into the Ares I and Orion designs.

NASA is also developing an integrated test and verification plan as part of its program preliminary design review in the next calendar year that includes a series of developmental tests to further refine and validate our designs. For example, on October 28, NASA completed the Ares I–X test flight at the Kennedy Space Center in Florida, and although the data is still being collected and processed from more than 700 onboard sensors, the data is already providing tremendous insight into the aerodynamic, acoustic, structural, vibrational and thermal forces that Ares I is expected to experience, knowledge that will contribute substantially to the reliability and safety of the Ares I design.

In closing, I would like to reiterate that safety is and always will be our number one priority in everything we do and that everyone at NASA is dedicated to ensuring that our astronauts are equipped to safely conduct the missions asked of them and that they are able to return safely home.

Chairwoman Giffords, I would be pleased to respond to any questions the member might have.

[The prepared statement of Mr. Hanley follows:]

PREPARED STATEMENT OF JEFFREY HANLEY

Chairwoman Giffords and Members of the Subcommittee, thank you for the opportunity to appear today to discuss NASA's next-generation human spaceflight program and the Agency's emphasis on continuing to improve safety factors for our most valuable assets—the men and women who dare to explore the mysteries of our universe. Everyone at NASA is dedicated to ensuring that these brave pioneers are equipped to safely conduct the missions asked of them, and that they are then able to safely return home to their loved ones. Simply put, safety is the first of our core values at NASA, and it is also the top priority of the Agency's Constellation Program.

As requested in your invitation to me to testify at today's hearing, my testimony will outline NASA's ongoing focus on safety matters with regard to human spaceflight, focusing primarily on how the Agency sought to improve crew safety for the Constellation Program above that achieved on previous crewed spacecraft. This has been accomplished by incorporating safety in all aspects of Constellation from the beginning of the design process. My testimony will also outline how the Constellation Program has progressed into the early developmental testing stages, and how data from those tests is being used to improve our models and to validate the rigorous safety requirements developed for the Constellation vehicles.

Columbia Accident Investigation Board and the Exploration Systems Architecture Study

In 2003, the Columbia Accident Investigation Board (CAIB) report provided NASA with guidelines for moving forward with our return to flight efforts. In addition to determining the causes of the Columbia accident, the CAIB also provided the Agency with a set of comprehensive recommendations to improve the safety of the Space Shuttle Program and to change the corporate culture of the Agency—changes that have positively impacted the Constellation Program. NASA has also established processes that enhance our ability to assess risk and to improve communication across all levels and organizations within the Constellation team.

More specifically, with regard to the design of the next-generation crew launch vehicle, the CAIB recommended that:

"The design of the system [that replaces the Shuttle] should give overriding priority to crew safety, rather than trade safety against other performance criteria, such as low cost and reusability, or against advanced space operation capabilities other than crew transfer."

In other words, the CAIB gave NASA clear guidance that the next-generation crew launch vehicle should be simpler and safer, and that crew safety should be the driving design principle. Now the question became, how did we meet this challenge? More specifically, how did we make a vehicle "inherently safe" while also protecting against residual risk, in a mass-constrained, highly-energetic system such as a launch vehicle? We started by going back to the basics, first identifying the known risks and hazards and then working to eliminate, or at least to minimize, each one of them. From there, the designers turned their attention to developing acceptable mitigation approaches for the residual risks. From the beginning, this complicated and lengthy process, known as risk-informed design, has been at the heart of NASA's Constellation Program.

However, before there was even a program known as Constellation, NASA used the CAIB guidance and other policy directives to initiate the Exploration Systems Architecture Study (ESAS) in 2005 with the purpose of assessing and defining the top-level requirements and configurations for crew and cargo launch systems, not only to support future lunar and Mars exploration programs, but also to support the International Space Station.

In conducting its review, the ESAS team focused on guidance issued by the Chief of the Astronaut Office in May 2004—particularly on one key statement, which states:

The Astronaut Office believes that an order-of-magnitude reduction in the risk of loss of human life during ascent, compared to the Space Shuttle, is both achievable with current technology and consistent with NASA 's focus on steadily improving rocket reliability, and should therefore represent a minimum safety benchmark for future systems. This corresponds to a predicted ascent reliability of at least 0.999.

Keeping in mind the CAIB recommendation of focusing on crew safety first, ESAS placed a premium on crew safety. All candidate crew launch vehicle concepts considered during ESAS included an escape capability referenced as a launch abort system or LAS. During the study, NASA eliminated any launch vehicle concept that did not approach at least a predicted probability for loss of crew (LOC) of 1 in 1,000 missions. In addition, concepts that would place the crew module in close proximity to the boosters and/or other potential sources of accident initiation were eliminated to improve the reliability of a LAS and to improve the likelihood of crew survival in the event of an accident during ascent. This process resulted in the selection of the single solid First Stage concept, which would later become known as the Ares I Crew Launch Vehicle. In the end, the potential for increased safety provided by Ares I (compared to other alternatives considered during ESAS) was based primarily on the simplicity of the First Stage.

As compared to the Space Shuttle, the Ares I will be a simpler vehicle to process prior to launch because NASA has designed the Ares Ito have fewer moving parts, thus requiring less hands-on labor prior to launch, and also reducing the potential for human error. In addition to the inherent safety associated with the rocket's simplified design, the Ares I integrated rocket will have a LAS for crew, as will be outlined in greater detail during the next section of this testimony.

The Constellation Program and Risk-Informed Design

In the Apollo era, crewed launchers were designed with the best level of expertise available, tested to exhaustion, and then robustness or redundancy was added to mitigate the residual risk. The goal was to make the design as reliable as possible, so that backup systems would never have to be used, and to make the backup systems as robust as possible to maximize the likelihood of crew survival and return, should a failure (anticipated or not) of the primary system or element take place. This approach worked, producing dramatic advances in reliability and crew safety, as proven, for example, when the Lunar Module did not experience a single anomaly on the final lunar mission, and the crew survived despite the explosion aboard the Command/Service Module during the Apollo 13 mission. However, as my colleague, Bryan O'Connor, will outline in his testimony, safety at NASA is also about more than design. NASA's focus on safety also includes ensuring that our crews and operators know how to deal with contingencies, and that, when someone has a concern about a safety issue, whether it be a crew member, a design team member etc. that there are clear paths for those who have dissenting opinions to raise their concerns to senior management.

Today, NASA's Constellation Program has a goal of increasing astronaut safety tenfold relative to Shuttle missions. While a seemingly daunting challenge, NASA believes that this goal is achievable for many reasons.

First, NASA is utilizing a multi-faceted design objective for safety that remains the same as during the Apollo era—design the system to be as inherently safe as we can make it, and then add backup to mitigate the predicted as well as unknown residual risk. This, along with aforementioned guidance issued by the Chief of the Astronaut Office in May 2004, was the starting point of the Constellation design team. As has been stated, inherent safety implies the elimination of hazards that have historically been associated with the operation of the type of system being designed. This, in turn, implies the systematic identification of the hazards associated with operation of the system alternatives being considered.

The key to a risk-informed design is integrating risk analysis into the design alternative evaluation and selection process in a fundamental way by using newly capable, logical, and phenomenological (or physics-based) computer models. These models help focus the design effort toward identifying and reducing or eliminating design hazards, which, in turn, helps NASA identify and develop mitigation approaches to address the residual risks. In addition, NASA recognizes that safety of an overall system can be improved by addressing human factors issues, which is why the Ares I Upper Stage and Orion designs have been developed to simplify and automate processing and operations as much as possible, thus reducing the potential for human error.

Second, unlike the Space Shuttle, the Orion crew capsule will have a LAS that will offer a safer and more reliable method of moving the entire crew out of danger in the event of an emergency on the launch pad or during the climb to Earth orbit. Mounted at the top of the Orion and Ares I launch vehicle stack, LAS will be capable of automatically separating the Orion from the launch vehicles and positioning the Orion and its crew for landing. In comparison, during Apollo, NASA had comparatively little experience and computational capability, and the abort effectiveness was estimated by comparison to escapes from high-performance military aircraft combined with the results of a few escape system tests. Today, with the flight tests combined with advanced simulation tools and advanced computers available, NASA can conduct a more thorough analysis. Specifically, the integrated abort system's effectiveness can now be calculated using computer models of the blast environment by employing more realistic, physics-based, simulations of abort conditions. While computer models and computational capability were much less capable during the Apollo era, today this calculation can be carried out with remarkable speed and accuracy given NASA's evolved engineering expertise and the computational power of our computers.

Third, Constellation has chosen to tightly interweave the design and safety team members into the decision making process. As a result, the Constellation team represents skills from safety and reliability engineering disciplines traditionally found under the Safety and Mission Assurance organizations, as well as engineers with backgrounds such as computational fluid dynamics, aerospace, and physics disciplines. The team has been given the clear direction to work daily with the design engineers to provide expertise and feedback via various assessments and analysis techniques throughout the design maturation process. This investment demonstrates a sincere commitment to the CAIB findings.

Finally, as a key element of our risk-informed design process, the Agency has an active risk-management process that identifies technical challenges early in the process and aggressively works solutions. The Program identified key risks during the risk management process and associated mitigation steps to inform the designs. Technical risks are identified by likelihood of occurrence and consequence. For example, NASA is currently working a thrust oscillation risk for the Ares I First Stage. This phenomenon is a characteristic of all solid rocket motors. NASA has made significant progress in identifying both primary and backup approaches to mitigate the oscillation effect, and we now believe that we have now baselined a passive mitigation technique. However, additional testing will continue to ensure we have the best mitigation prior to making the final decision at the Constellation Program's Preliminary Design Review (PDR) early next year. With regard to the Upper Stage, the J–2X engine remains a priority, with the focus being on achieving needed performance requirements while also incorporating modem approaches (e.g., materials, manufacturing, electronics, etc) into this Apollo-era heritage hardware.

In choosing a Shuttle-derived architecture, NASA recognized from the outset that some of the heritage hardware would need to be modified or replaced so as to achieve improved safety, reliability, as well as to meet needed performance and lower lifecycle costs. At the same time, the Agency recognized that leveraging systems with human-rated heritage would reduce the uncertainties and risks associated with developing a new human-rated crew launch vehicle. For example, the Ares I First Stage consists of a five-segment reusable solid rocket motor (RSRM), an aft skirt, a forward skirt, and a frustum. The five-segment RSRM is an evolutionary development from the four-segment solid RSRM strap-ons currently utilized to power the Space Shuttle. As a result, the Constellation Program is building on the proven track record of this heritage hardware. There have been 252 solids flown in the Shuttle Program with one failure (Challenger STS–51L). The Ares I also benefits from the improvements in the RSRMs that have resulted from recovery and post-flight inspections along with modifications that have been made to the Shuttle boosters. The Ares I booster also will continue the protocol of recovery and post-flight inspection that began in the Shuttle Program.

The J–2X engine would be used for both the Ares I and Ares V vehicles, thus creating a common link between the two vehicles that is based on evolved heritage hardware, specifically the powerful J–2 engine that propelled the Apollo-era Upper Stage on the Saturn I–B and Saturn V rockets, and the J–2S that was developed and tested in the early 1970s. In addition, the J–2X will leverage knowledge from the Delta IV's RS–68 by incorporating manufacturing techniques from the RS–68 into the J–2X engine. However, NASA recognizes that there are also challenges involved with utilizing and integrating heritage systems into new vehicles, so for the J–2X, NASA has taken steps to increase the amount of component-level testing, to procure additional development hardware, and to work to make a third test stand available to the contractor earlier than originally planned.

Already, the Ares I risk assessment and failure analysis teams have provided input and/or impacted the outcome of Ares I design issues, trades, or risks on numerous challenges, including:

- Abort triggers study: Provided LOC and Abort Effectiveness assessments, including engineering models and timing, to determine what potentially catastrophic scenarios warrant abort sensors and software algorithms;
- Separation study (booster deceleration motors): Hazard analysis combined with probabilistic design analysis led to the design decision to increase the number of booster deceleration motors from eight to 10; and,
- The Hazards Team identified that the First Stage and Upper Stage designs failed to meet properly at the interface flange (due to differing number of bolts) and a re-design was instituted. The team provided an assessment to Upper Stage that resulted in clocking of the hydrogen and oxygen vents to improve separation distance.

While NASA awaits further direction from the President and Congress with regard to the future of human spaceflight, the Agency is continuing to pursue our current programs, per direction from the Office of Science and Technology Policy. Currently, the Constellation Program is progressing through an active phase of hardware and software tests and, as tests are completed and data analyzed, our models will be updated, allowing us to improve safety and improve systems performance. At the same time, we are investing heavily in risk-reduction hardware and activities that will help calibrate and refine our models and simulations related to the Ares I and Orion—data that is essential to incorporate as early as possible into vehicle designs, based on the Program's risk-based design approach. NASA is developing an Integrated Test and Verification plan that includes a series of developmental tests to further refine and validate our designs. Test flights, for example, are being designed to include several hundred measurement points that will characterize the actual operating environment and system performance in the most stressing of cases. NASA is in the process of continuing to refine this test and verification strategy prior to the Program's PDR early next year, when the Integrated Test and Verification plan will be baselined.

Following are just a few examples of recent and upcoming developmental tests which have yielded, or are expected to yield, significant amounts of data that will be incorporated into our risk-based design effort:

- In September 2009, NASA and ATK conducted the first test of the Ares I's five-segment development motor in Promontory, Utah. This test provided NASA with valuable thrust, roll-control, acoustics and vibration data as engineers continue to design the Ares I. In all, seven ground tests are scheduled for the five-segment booster.
- In October 2009, the Ares I–X test flight took place at Kennedy Space Center in Florida. Although data is still being collected and processed from more than 700 on-board sensors, preliminary results show that the vehicle performed precisely as it was meant to perform. Early data shows that the vehicle was effectively controlled and stable in flight. Thrust oscillation fre-

quencies and magnitude data from the Ares I–X flight are consistent with measurements from recent Shuttle flights that were instrumented, leading us to conclude that the oscillation vibration on the Ares I would be within the bounds that the Ares I is currently being designed to. When assessment of this data is finalized, we believe it will provide tremendous insight into the aerodynamic, acoustic, structural, vibration, and thermal forces that Ares I is expected to experience—knowledge that will contribute substantially to the reliability and safety of the Ares I design, as well as to enhancing NASA's modeling capabilities for future vehicles.

- In March 2010, NASA plans to perform its first developmental test of the Orion LAS at the White Sands Missile Range, New Mexico. This test will validate the LAS design approach and will contribute substantially to the Orion's final designs for reliability and safety. NASA plans a series of tests to characterize the LAS. The Pad Abort I test is the first of these tests, and it will address what happens if an emergency occurs while the Orion and the launch vehicle are still on the launch pad. Other tests will determine how the LAS performs in critical parts of the flight regime.

Human Rating and the Constellation Vehicles

The launch of any spacecraft is a very dynamic event that requires a tremendous amount of energy to accelerate to orbital velocities in a matter of minutes. There also is significant inherent risk that exposes a flight crew to potential hazards that could be catastrophic, if not controlled. Therefore, through a very stringent process of human rating, NASA attempts to eliminate hazards that could harm the crew, control the hazards that do remain, train the crews and operators to react appropriately, control the manufacturing and test of all components to minimize errors, and provide for crew survival even in the presence of system failures. Spaceflight vehicles are cleared by NASA to carry crew for missions that are associated with specific mission and performance requirements in an engineering flight test environment. It is also important to note that certification is made for an entire spaceflight system (i.e. Ares I, Orion, and associated ground support infrastructure count as one entire system), and not for specific elements of a system. NASA is currently in the process of developing those specific mission requirements for Ares I and Orion.

To guide the evolution of human rating requirements for any mission, NASA is developing Agency-level requirements documents. However, human rating a spaceflight system is not as easy as following one document. Instead, it is an intricate, continuing process, involving the translation of requirements into designs that can be built, tested, and certified for flight, and an understanding of risks with mitigation approaches in place. However, the challenge to projects such as Ares I and Orion is that there is no single document that spells out what they should do to receive a human rating certification from the Agency.

NASA is investing FY 2009 Recovery Act funds to begin development of a more concise set of NASA human rating technical requirements. These requirements would be applicable to NASA developed crew transportation systems as well as commercially-developed crew transportation systems for use by NASA. This task is being performed by a team comprised of representatives from NASA's human spaceflight programs, the Astronaut Office, Agency technical authorities, including the Office of Safety and Mission Assurance. We are also consulting with other Government partners such as the Federal Aviation Administration and with commercial stakeholders.

Conclusion

In closing, I would like to quote from the October 2009 Review of U.S. Human Spaceflight Plans report: "Human space travel has many benefits, but it is an inherently dangerous behavior." NASA wholeheartedly endorses this statement because it is a challenge we live with day in and day out. Safety is and will always be our number one priority in everything we do. That is why the Constellation Program has employed a continuous risk-informed design process, and that is why our designs are being developed with an overriding priority given to crew safety at every stage of the design and operational process.

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

Chairwoman GIFFORDS. Thank you, Mr. Hanley, for your testimony.

Next we will hear from Mr. Marshall.

STATEMENT OF JOHN C. MARSHALL, COUNCIL MEMBER, AEROSPACE SAFETY ADVISORY PANEL, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. MARSHALL. Chairwoman Giffords and other distinguished members of the committee, good morning. Thank you again for inviting the ASAP to testify before your Subcommittee today.

As you may know, today's topic has been area of interest that the ASAP has focused on for a sustained period. Most recently we visited SpaceX and Orbital Sciences, both currently commercial providers to NASA for logistics re-supply to the Space Station, to discuss firsthand their approach to integrating safety into their vehicles.

Of course, interest in using the commercial space industry to fulfill NASA's crew delivery services to low earth orbit, LEO, has spiked because of the recent Augustine report recommendations that appropriate consideration be given to turning the service over to the commercial sector. In making this recommendation, they also noted that while safety never can be absolutely assured, safety was assumed to be a given. The ASAP believes this assumption was premature and an oversimplification of a complex and challenging problem in that there is no cookie cutter approach to safety in space nor is it a "given."

NASA's Procedural Requirements, NPR 8705.2b, identifies the human rating process for NASA space systems. It specifies a risk-based approach to evaluate a system against pre-established requirements. It does not, however, establish what those requirements are. NASA emphatically intends this document to be a starting point with detailed requirements to be tailored specifically for each NASA human spaceflight program including a possible NASA-crewed COTS mission.

Because it is illogical to rely on commercial providers to develop their own requirements for contractual services on human spaceflight to NASA, the ASAP strongly believes that specific criteria should be developed to establish how safe is safe enough for these services. In addition, it is imperative that the COTS enterprises understand in detail how verification of compliance shall be demonstrated. This just now is being developed by NASA.

With the above background, I will now briefly address the four questions that you asked us to talk to. First was, what do you consider to be the most safety-related issues that will have to be addressed if NASA were to consider using commercial providers for crew transportation and station crew rescue services. The ASAP believes that ensuring the safety of NASA's astronauts that we send into space may be the hardest part of commercialization of the LEO crew transportation mission. Significant challenges to be solved include first establishing detailed safety requirements that NASA deems essential to safe flight. There must be clear and enforceable form that can be placed into a contract and tested for compliance. Second, because no launch vehicle can be considered truly safe in the conventional sense of the word, establishing minimum acceptable safety levels to guide systems safety design and a baseline for both NASA and their contractors as to what is safe enough is critical. Third, much of the inherent safety of spacecraft design depends upon choices and decisions where risks are weighed against performance costs and schedule. A process to ensure that all the potential hazards are properly vetted by both the government and contractors is important. This will require more than the hands-off approach that some envision. And finally, establishing a disciplined process-related checks and balances so that NASA can verify that the contractor has demonstrated compliance with the launch vehicle designs requirements is necessary.

The next question was, what safety standards should commercial entities have to meet if they are chosen by NASA to carry U.S. government astronauts to low earth orbit and what will be required for verification? As noted previously, NASA's NPR procedures prescribe a human rating process for NASA's space system. This document, changed in 2008, represents a significant and substantive shift from the prescriptive approach to one that applies good engineering standards and judgments. Prescriptive standards describe how things get done and are applied rigidly. A good-judgment approach offers less specific direction and guidance. The ASAP sees advantages in both but with a clear need for written guidance of record of change and direct connectivity to establish time-tested engineering standards.

In this regard, it is the ASAP position that any new standards for commercial entities should begin with NASA's NPR and that the human rating for each system must appropriately be tailored to combine robust design, solid engineering, and testing along with a system safety approach for examining options to minimize the probability and impact of failure. Doing so will in the end provide both higher reliability and safety for human life. With respect to demonstration, verification and certification, the ASAP agrees that each of these actions must be performed for both government and commercial programs prior to NASA's use. It also is the ASAP's position that NASA is the best qualified to be the oversight body for each of these actions.

Three: What would be required to certify the airworthiness of any commercially provided crew transportation system or station rescue service prior to its use by U.S. government astronauts? How long do you anticipate such certification would take? As you know, airworthiness certification is a process that is carried out by a regulatory body. Typically, it is an agency such as the FAA or government organization. Certification gives assurance that necessary practices, policies and criteria have been satisfied to protect the safety of the crew, passengers and the public from harm due to a design or operational flaw in the functioning of the vehicle. For certification of any commercial or government space transportation system, it is clear that the human rating standard would have to be understood by all of the participating parties once those standards are known and it is incumbent upon any party presenting a vehicle for use to present compelling evidence that the standards have been met. That evidence can take several forms, most of which are covered by standard industry practices. In the case of crew delivery, cargo delivery, rescue from the station, it is well to remember that it must not only be certified for its own safe operations in itself but must also be able to approach, dock and interface with the station without presenting a hazard to that vehicle as well.

In response to the question of how long such a process would take, our experience indicates that this is a function of two things. First, there must be clarity and mutual understanding the requirements and a process for verifying the requirements have been met. Second, there must be an openness and degree of sharing of co-operation of the design process to the reviewing authority. Of course, the completion of the review remains directly proportional to the complexity and uniqueness of the proposed system.

Finally, in the annual report that ASAP published for 2008, the ASAP is concerned about human rating requirements substance, applications and standards NASA-wide. What is the basis for this concern? The basis for our concern is that in more than two years into the COTS program, efforts to develop human rating standards for a COTS–D-like program have only just begun and no guidance thus far has been promulgated. Therefore, it is premature to consider any potential COTS–D vehicle as being human rated. If COTS entities are to ever provide the level of safety expected for NASA crews, it is imperative that NASA's criteria for safety design of such systems quickly be agreed upon and provided to current or future providers.

I would be happy to respond to any other questions you or any other members may have.

[The prepared statement of Mr. Marshall follows:]

PREPARED STATEMENT OF JOHN MARSHALL

Chairwoman Giffords and other distinguished members of the Subcommittee, good morning. Thank you for inviting the Aerospace Safety Advisory Panel (ASAP) to testify again before your Subcommittee on the topic of ensuring human space flight safety in future government and potential future non-government space transportation systems.

As you may know, this topic has been an area of interest that the ASAP has focused on over a sustained period. Most recently we have visited the Space Exploration Technologies Corporation (Space X) and Orbital Sciences Corporation, both currently commercial providers to NASA for logistical re-supply to the International Space Station (ISS)—and possible Commercial Orbital Transportation Services (COTS–D) providers in the future, to discuss firsthand their approach towards integrating safety into their vehicles.

Of course interest in using the commercial space industry to fulfill NASA crew-delivery services to Low Earth Orbit (LOE) has spiked because of the recent Augustine report recommendation that appropriate consideration be given to turning this service over to the commercial sector.

Unfortunately, in making this recommendation they also note that while human safety never can be absolutely assured, safety was assumed to be "sine qua non," or "a given" in their recommendation. The ASAP believes this assumption is premature and over simplifies a complex and challenging problem, in that there is no "cookie-cutter approach" to safety in space. Nor is it "a given."

We further believe that since NASA has given serious consideration only recently to what their approach will be in establishing human rating requirements for a vehicle that is occupied by NASA personnel, the commercial sector may be substantially behind in addressing human rating requirements for the future.

NASA's Procedural Requirements (NPR) 8705.2b identifies the human rating requirements for NASA's space systems. It contains recently updated requirements and captured lessons learned that are applicable to the development and operation of crewed space systems. NASA emphatically intends this document to be a starting point with detailed requirements to be tailored specifically for each NASA human spaceflight program, including a possible NASAcrewed COTS mission. Additionally, NASA specifically caveats that the results of any tailored effort for a NASA-crewed COTS mission could be different from that developed for a NASA program.

Because it is illogical to rely on commercial providers to develop their own requirements for contractual services on human spaceflight to NASA, the ASAP strongly believes that specific criteria should be developed to establish how safe is "safe enough" for these services, including the need to stipulate directly the acceptable risk levels for various categories of activity. In addition, it is imperative that the COTS enterprises understand in detail how verification of compliance shall be demonstrated. This too is just now beginning development by NASA.

With the above background, I will now briefly address the four specific questions that you posed to the panel:

1. What do you consider to be the most significant safety-related issues that will have to be addressed if NASA were to consider using commercially provided crew transportation and International Space Station (ISS) crew rescue services?

Response: Ensuring the safety of the NASA astronauts that we send into space may be the hardest part of commercializing LEO crew transportation. The significant challenges to be solved include:

- Establishing detailed safety requirements that NASA deems essential to safe flight. These must be in a clear and enforceable form that can be placed on contract(s) and tested for compliance.
- Because of their energy, speed, and complexity, no launch vehicle can be considered truly "safe" in the conventional sense of the word. Therefore, establishing minimum acceptable safety levels to guide system designs and set the baseline for both NASA and their contractors as to what is "safe enough" is critical.
- Even with clear safety requirements and levels, much of the inherent safety of complex systems like spacecraft depends upon the design choices and decisions where risks are weighed against performance, costs, and of course, schedules. An open and effective system has been developed within NASA to accomplish this. A similar process needs to be institutionalized by any commercial provider as well, whereby all potential hazards are properly vetted by both government and contractors. This will not be easy and may require more than the "hands off' approach envisioned by some.
- Establishing disciplined program and process-related checks and balances so that NASA can verify that the contractor has evidence of compliance with the launch vehicle design requirements in the as-built vehicle and successful completion of the activities necessary to demonstrate mission readiness.

2. What safety standard should commercial entities have to meet if they are chosen by NASA to carry U.S. government astronauts to LEO, and what will be required to verify compliance?

Response: As noted previously, NASA's NPR 8705.2b prescribes human rating requirements for NASA's space systems. This document, changed in 2008, represents a significant and substantive shift from a prescriptive approach to one that applies good engineering judgment. Prescriptive standards describe how to do things and are applied rigidly. Good judgment offers less specific direction and guidance. The ASAP sees advantages in both, but with a need for clear written record-of-change and direct connectivity to establish and time-tested engineering standards.

In this regard, it is the ASAP's position that any new standards for commercial entities should begin with NASA's NPR—the "gold standard" if you will—and that the human rating for each system *must* appropriately be tailored to combine testing, solid engineering, and robust design along with a system safety approach for examining options to prevent and minimize the impact of failures. Doing so will, in the end, provide both high reliability and safety of human life.

With respect to demonstration, verification, and certification, the ASAP agrees that each of these actions must be performed for both government and commercial programs prior to NASA's use. Further, it also is the ASAP position that NASA is best qualified to be the oversight body for each of these actions as today only NASA has the competence in hand to effectively audit the complex technical work required.

3. What would be required to certify the "airworthiness" of any commercially provided crew transportation and ISS rescue service prior to its use by U.S. government astronauts? How long do you anticipate such certification would take?

Response: Similar to other certifications, "airworthiness certification" is a process that is carried out by a regulatory body. Typically that is an agency such as the Federal Aviation Administration or other governmental body that acts in the interest of the party having the most critical concern in the outcome. Certification is an oversight process, which serves to give assurance that necessary practices, policies, and criteria have been satisfied to protect the safety of the crew, passengers, and the public from harm due to a design or operational flaw in the functioning of the vehicle.

Building on this basic principal, for certification of any commercial or government space transportation system, it is clear that human rating standards that have been discussed in prior answers would have to be developed, published, and understood by all participating parties.

Once those standards are known, it then is incumbent on any party presenting a vehicle for utilization covered under the certification process to present compelling evidence that the standards have been met. That evidence can take several forms, most of which are covered by standard industry practice.

Testing typically is used to verify that the design meets the standard. The simplest of these would be the proof testing of pressure vessels that has been common for most of the last century. When testing is not possible because it is either too dangerous or involves conditions that cannot be set up in the laboratory, then analysis or sub-scale experiment is accomplished. Finally, well-validated analysis (finite element structural analysis, computational fluid dynamics, physics based simulations) can form an acceptable mechanism to show compliance.

In the case of crew delivery, cargo delivery, and rescue from the ISS it is well to remember that not only must the certified vehicle be safe in and of itself, but it must be able to approach, dock, and interface with the ISS without presenting a hazard to that vehicle as well. This means that besides the certification standards for the vehicle in question it will also have to meet additional requirements for operation in the vicinity of and docking to/departing from the ISS. These standards have already been developed and thus any new vehicle certification would also have to meet these requirements.

In response to the question of how long such a process would take, our experience indicates that this is most certainly a function of two things. First, there must be clarity and mutual understanding of the requirements and a process for verifying that the requirements have been met. Second, there must be openness and a degree of sharing/cooperation/transparency of the design process to the reviewing authority. Waiting until the design is complete and all parts and pieces are in place, sealed, and potentially inaccessible before inviting review of the design would be a recipe for failure. Conversely, providing periodic design reviews, openness for witnessing testing, clarity of analytical methods as the work progresses can assure a process with minimum to no delay. If the data is delivered as requested, testing is witnessed as it takes place, and the analysis uses known and validated methods, the finalization of the review remains directly proportional to the complexity and uniqueness of the proposed system. Missing or absent data, analysis that is incorrect or faulty, and tests that have been done but not confirmed can extend the process indefinitely.

4. In its annual report for 2008, the ASAP stated "*the ASAP is concerned about human rating requirements substance, application, and standardization NASA-wide*." What is the basis of ASAP's concern?

Response: The basis for our concern is that more than two years into the COTS program, efforts to develop human rating standards for a COTS–D like program have only just begun and no guidance thus far has been promulgated. If COTS entities are ever to provide the level of safety expected for NASA crews, it is imperative that NASA's criteria for safety design of such systems immediately be agreed upon and provided to current or future COTS providers.

As a minimum, the ASAP believes that NASA should begin a dialogue with the funded COTS partners to address requirements for human rating. Additionally, NASA needs to clarify how much or how little they will be involved in the design, approval and operation of the NASA-crewed vehicles in order to verify that the funded COTS partners are compliant with the human rating requirements. The ASAP recommends the agency be "hands-on."

NASA has indicated that they are considering a tiered or stair-step approach in addressing the technical review and approval processes to confirm safe flight and operational readiness, starting first with some level of technical insight for the unmanned services for routine supplies, then with greater insight for unmanned services involving high-valued cargo, and finally building up to the technical insight and process to be used for a NASA-crewed COTS mission. In modeling the COTS tiered technical insight processes, NASA will use its experience gained in the ISS program for transfer of routine supplies, and in the launch services program for commercial Expendable Launch Vehicle launches of high valued payloads. The ASAP concurs with this methodology.

Finally, as part of the launch certification requirements, NASA should immediately identify the number of launch successes that COTS partners will need to achieve with the unmanned vehicle in order to demonstrate the required vehicle reliability for a NASA-crewed launch. In developing the criteria for manned launch vehicle certification, NASA may also need to address whether and how the successful flights and results from the COTS ISS cargo reservicing and NASA launch services programs, can provide evidence for consideration in assessing launch reliability for NASA-crewed vehicle.

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, Mr. Marshall. It is good to have you back.

Mr. Alexander.

STATEMENT OF BRETTON ALEXANDER, PRESIDENT, COMMERCIAL SPACEFLIGHT FEDERATION

Mr. ALEXANDER. Chairwoman Giffords, Ranking Member Olson, distinguished members of the Subcommittee, thank you for the opportunity to testify this morning on behalf of the 20 member organizations of the Commercial Spaceflight Federation. We appreciate the Committee's longstanding support of commercial space.

Commercial crew transportation is complementary, not competitive, with NASA's mission and it is crucial to the future of our Nation's human spaceflight program for several reasons. First, after shuttle retirement, the United States will not have the capability to launch humans into space for likely six to seven years. Entering this gap, we will send billions of dollars overseas as we purchase seats on Russian vehicles at $51 million a seat and rising. A commercial crew can help prevent future Russian price increases, preserve redundant access to the space station and potentially shorten the gap. Second, enhanced commercial spaceflight will allow us to more fully utilize the space station, which is just now being completed. Third, commercial missions to low earth orbit will allow NASA to focus its resources and expertise on exploration beyond low earth orbit.

Commercial crew has been endorsed by a long line of Presidents and Congresses from the 2004 Vision for Space Exploration to the 2005 and 2008 NASA Authorization Acts. As such, it should come as no surprise that the Augustine committee stated, "There is little doubt that the U.S. aerospace industry has the technical capability to build and operate a crew taxi to low earth orbit."

Just as important, the committee stated their unequivocal belief that commercial spaceflight could be done safely. Indeed, safety is paramount to everyone in this industry. A group of 13 former NASA astronauts recently wrote in the Wall Street Journal that "We believe that the commercial sector is fully capable of safely handling the critical task of low earth orbit human transportation."

A taxi service to low earth orbit is a less difficult, more narrowly focused mission than the Orion Crew Exploration Vehicle and can therefore have more robust margins. For these reasons, commercial vehicles can be more cost-effective for Space Station operations without sacrificing safety.

In order to meet stringent safety goals, NASA and industry must agree upon a detailed, thoughtful plan. The commercial spaceflight industry believes the following four principles are key. First, demonstrated reliability through a robust test program is crucial. Robust testing throughout development and production is necessary to demonstrate confidence in the overall system. Commercial crew systems will only begin crewed flights once reliability has been demonstrated through multiple successful test flights without crew. Demonstrated launch reliability is essential for overall safety. The Atlas family, for example, has had over 90 consecutive successes. The Atlas V has a perfect record of 19 successful launches. And the Falcon 9 will have launched more than a dozen times for cargo and satellite missions before crew missions begin.

Second, robust safety will require additional human rating of the launch vehicle and a reliable crew escape system to protect the crew in the event of a launch vehicle anomaly.

Third, clear safety standards and requirements are crucial. It is vitally important that NASA and industry agree on the safety requirements up front and this dialog must begin in earnest now. NASA's human rating requirements document will serve as a starting point for this dialog but must be tailored for commercial systems just as it is for NASA-developed vehicles. NASA is currently reviewing their applicability to commercial systems and the commercial spaceflight industry is also conducting a similar review.

Finally, let me address government oversight. Any commercial crew program must be conducted under the current regulatory regime established by law, namely FAA licensing. FAA licensing is important to ensuring a consistent regulatory regime for both government and commercial missions, which is key to attracting private investment and non-NASA customers. While the FAA would retain the overall licensing authority, NASA would maintain oversight as the customer. In particular, NASA would establish astronaut safety requirements in consultation with industry, establish mission-unique requirements such as crew capacity and requirements for space station docking, and most importantly, have final approval authority over the launch of NASA astronauts, which would be granted only after NASA is satisfied that the vehicle is safe, just as NASA does for today's shuttle missions.

In conclusion, we firmly believe that NASA and commercial industry can and must work together to develop safer human spaceflight capabilities. We must begin that dialog now.

Thank you for the opportunity to be here today and I look forward to your questions.

[The prepared statement of Mr. Alexander follows:]

PREPARED STATEMENT OF BRETTON ALEXANDER

Introduction

Chairwoman Giffords and distinguished members of the Space and Aeronautics Subcommittee, thank you for the opportunity to testify. I am pleased to be here.

The Commercial Spaceflight Federation is an association of 20 leading businesses and organizations working to make commercial human spaceflight a reality. Our members include developers and operators of orbital spacecraft, suborbital spacecraft, and the spaceports from which they fly. Our membership also includes product and service providers for human spaceflight training, medical, and life support needs. Our mission is to promote the development of commercial human spaceflight, pursue ever higher levels of safety, and share best practices and expertise throughout the industry. One goal of all of our member organizations is to greatly increase the number of people that fly into space, generating new economic activity here on Earth.

Significant investment has already been committed to the development of commercial human spaceflight. According to a recent survey done by The Tauri Group, \$1.46 billion in investment has been committed to commercial human spaceflight activities to date. Coupled with the more than \$500 million in development funding provided by NASA under the Commercial Orbital Transportation Services, or COTS, program, more than $2 billion has been pledged for the development of commercial spaceflight capabilities. I want to take this opportunity to thank the Congress and NASA for your support of the COTS program.

In my testimony today, I will address the safety and oversight questions relating to commercially procured crew services. In order to understand these issues, it is important to first discuss the context of commercial spaceflight. My testimony covers the following key topics:

Summary of Key Points

1. Commercial crew transportation to Low Earth Orbit (LEO) is a goal endorsed by the Vision for Space Exploration (2004), the Aldridge Commission (2004), the 2005 NASA Authorization Act, the 2008 NASA Authorization Act, and the Augustine Committee.
   - Commercial crew is complementary, not competitive, with NASA activities, as commercial crew transportation to LEO will allow NASA to focus its unique resources on the more difficult task of beyond LEO exploration.
   - After shuttle retirement, the United States will send billions of dollars overseas to purchase seats on Russian vehicles during the gap in U.S. government launch capability. Only commercial crew allows us to reduce the gap, prevent future Russian price increases, and preserve redundant access to the Space Station.
2. Safety is paramount for the commercial spaceflight providers. Indeed, commercial vehicles such as Atlas V and Delta IV, developed with substantial private funding and engineering expertise, are already trusted to launch key government national security assets upon which the lives of our troops overseas depend.
3. Since computer calculations of vehicle safety cannot account for most of the root causes of accidents historically, such as human error or design flaws, and since even reliable vehicles have historically suffered a period of "infant mortality," the commercial spaceflight industry believes that safety must include the following:
   - Demonstrated reliability from orbital flight tests of the full system
   - Not placing crews on initial flights, since early flights are historically most risky
   - A highly reliable crew escape system
   - Standards-driven design and operations
4. Industry believes that the safety of commercial spaceflight must be greater than that of any vehicle currently in operation today. In addition to the FAA's existing regulatory authority, as codified in U.S. law, industry will satisfy customer-specific requirements levied by NASA in partnership with industry. This process has already begun with the cooperation of the stakeholders involved.
5. NASA and FAA will be there every step of the way, and will have oversight during design, testing, manufacturing, and operations. As codified in existing U.S. law, a licensing, rather than certification, regime is appropriate for these vehicles.

Government *Beyond* LEO, Commercial *to* LEO

Support and encouragement for the commercial development of space, including commercial space transportation services, has been a cornerstone of civil space policy for decades. It has been endorsed by numerous Presidential Administrations and Congresses, and by both parties. A quarter-century ago, the law that created NASA, known as the Space Act, was amended to specify that NASA is to "seek and encourage, to the maximum extent possible, the fullest commercial use of space" and "to encourage and provide for Federal Government use of commercially provided space services and hardware." Additionally, the Commercial Space Act of 1998 directed all agencies including NASA to "acquire space transportation services from United States commercial providers whenever such services are required in the course of its activities."

In 2004, following the Space Shuttle *Columbia* accident, the Vision for Space Exploration (U.S. Space Exploration Policy, National Security Policy Directive-31), announced by President George W. Bush on January 14, 2004, directed NASA to:

- *"Develop a new crew exploration vehicle* [now called Orion] *to provide crew transportation for missions beyond low Earth orbit."*
- *"Acquire"*—and it's important to note here the intentional use of the word "acquire," not "develop"—*"cargo transportation as soon as practical and affordable to support missions to and from the International Space Station."*
- And again *"Acquire crew transportation to and from the International Space Station, as required, after the Space Shuttle is retired from service."*
- To put further emphasis on this point, the policy directed NASA to *"Pursue commercial opportunities for providing transportation and other services supporting the International Space Station . . . ."*

This was reinforced by the Aldridge Commission on implementation of the Vision which recommended in June 2004 that *"NASA recognize and implement a far larger presence of private industry in space operations . . . most immediately in accessing low-Earth orbit."*

This fall, the Review of U.S. Human Space Flight Plans Committee endorsed the development of commercial crew capabilities as the primary means to transport astronauts to and from the International Space Station. Astronaut Sally Ride, a member of the Committee, stated, "We would like to be able to get NASA out of the business of getting people to low Earth orbit."

Given the above history, the Augustine Committee's endorsement of the development of commercial crew capabilities should come as no surprise. Commercial crew and cargo to the Station has always been part of the Vision for Space Exploration, which had at its most fundamental core the philosophy that government should explore beyond low Earth orbit and the commercial sector should provide transportation to low Earth orbit. As such, commercial is complementary to government activities, not competitive.

Congress has noted the importance of commercial spaceflight as well, as the 2005 and 2008 NASA Authorization bills endorsed commercial cargo and crew. The 2005 NASA Authorization Act directed NASA to "*work closely with the private sector, including by . . . contracting with the private sector for crew and cargo services, including to the International Space Station, to the extent practicable.*" The 2008 NASA Authorization Act directed NASA to initiate a commercial crew program and to fund "*two or more commercial entities . . . for a crewed vehicle demonstration program."*

To its credit, NASA has already been acquiring cargo delivery to the Station. First, NASA invested $500 million in the development of two commercial systems, with additional investment contributed by the companies themselves, through the Commercial Orbital Transportation Services (COTS) program. After several years of development, NASA demonstrated its confidence in the commercial cargo sector by declining to purchase additional Russian cargo flights after 2011 and instead awarding over $3 billion in domestic Commercial Resupply Services (CRS) contracts for Space Station cargo. In just four years, commercial cargo has transitioned from a small initiative to a program that is crucial to the continued existence of the Space Station. The bottom line is that commercial space services are on the critical path for cargo to the Station and NASA has a vested interest in its success.

With commercial cargo now on the critical path for the Space Station, it is time to consider the value of commercial crew services for Space Station as well.

Commercial Crew is Essential to Mitigate the Gap

Despite having an option for crew transportation in the COTS program—the so-called Capability D option—NASA has not yet invested in the development of full commercial crew capabilities, opting to prove out cargo services first with the possibility of crew later. The case for beginning a commercial crew program has grown stronger in the years since the COTS cargo program began:

- Flights of the Atlas, Delta, Falcon, and other vehicles have helped mature the capabilities that will be needed during a future commercial crew program;
- Commercial companies have invested their own internal R&D and study money to explore commercial crew;
- NASA's $50m CCDev program is revealing the strength of interest in commercial crew by both large and medium-sized companies in the aerospace industry;

- And the Augustine Committee notes that "the use of commercial vehicles to transport crews to low-Earth orbit is much more of an option today than it might have been in 2005."

Today, three years after the award of the COTS Space Act Agreements (SAAs), we no longer have the luxury of time. The Space Shuttle will be retired next year, or shortly thereafter, while the first flight of Ares I and Orion has slipped to at least 2017, according to the Augustine Committee. In fact, the Committee added that if the Space Station is extended to 2020 as seems likely, the first human launch of Ares I would slip further, even if NASA receives the extra money the Committee recommended. As a result, we will be dependent on the Russians for crew transportation to the International Space Station for at least five years, if not longer.

Given that Ares I/Orion is not likely to be ready until at least 2017 and that system is optimized for the unique requirements of exploration beyond Low Earth Orbit, we believe a vibrant U.S. commercial crew program is essential for avoiding a sole-source reliance on the Russian Soyuz vehicles in the interim. In fact, we have already purchased rides on Russian Soyuz spacecraft at the price of $51 million per seat, having taken extraordinary measures and changing U.S. nonproliferation laws to allow these payments. Buying crew services from U.S. industry should not be viewed as nearly so extraordinary.

Moreover, Russia's prices are rising and are certain to increase once we become totally reliant on them. A robust U.S. commercial crew program, however, will apply competitive pressure on Russia to keep costs down. Also, NASA's ability to purchase Soyuz vehicles from Russia expires in 2016. Ares/Orion is not likely to be ready by then. It is impossible to know with certainty whether another extension of INKSNA (Iran, North Korea, and Syria Nonproliferation Act) will be granted by Congress at that time. Pursuing a commercial option to meet near-term needs for Station could help alleviate the risks inherent in Russian reliance. By not pursuing commercial, it is almost certain Congress will have to re-address the INKSNA issue.

Complementary, Not Competitive

Commercial crew is complementary, not competitive with NASA's exploration program. NASA should once again be focused on exploration beyond low Earth orbit, and turn over to the private sector the repetitive tasks of resupplying the Station—and that includes transporting people there too. Not just a few people, but a multitude of researchers, engineers, and technical specialists. We need more activity in low Earth orbit, not less.

Exploration beyond low Earth orbit will not be sustainable—if it happens at all—without a vibrant commercial sector providing transportation services to and from low Earth orbit. The Center for Strategic and International Studies recently released a report on the U.S. space program which stated: "*Without commercial engagement, exploration will . . . continually expand the scale of government obligations, rather than keeping civil space programs focused on the frontiers of exploration*." None of us believes that the government can continuously expand the obligations and expectations of our civil space program without reaching a breaking point, regardless of where one thinks that breaking point is. The additional resources and capabilities of the private sector are essential.

Commercial to LEO is Less Difficult than Exploration Beyond LEO

The Augustine Committee, like the Aldridge Commission before it, found that the commercial sector is ready and capable to handle the task of transportation to Low Earth Orbit. Low Earth Orbit is less difficult, and therefore more achievable by the private sector, compared to the more capable tasks that NASA's current exploration vehicles are optimized for.

Thus, it is not an apples-to-apples comparison to compare a commercial crew capability to the Orion crew exploration vehicle. Rather, it is apples and oranges, because transporting crew to and from the International Space Station requires a far less complex spacecraft than exploring beyond low Earth orbit. It is akin to developing a Gemini spacecraft for low Earth orbit, rather than an Apollo spacecraft for reaching the Moon. The Orion spacecraft, for example, must reenter the atmosphere at one-and-a-half times orbital velocity, encountering heat loads nearly double those when returning from low Earth orbit, and Orion must do so with far more precision. Orion must also operate autonomously in lunar orbit untended while astronauts explore the surface, acting more like a space station than a crew taxi, and requiring more complex onboard vehicle systems.

As a result, the Orion spacecraft is a 25 metric ton (mT) vehicle, whereas spacecraft designed solely for low Earth orbit transportation are expected to be in the 8–12 mT range, or less than half the size for the same number of crew. Quite simply, you don't take an 18-wheeler to the corner grocery store. Nor do you drive a Formula One racecar. The Orion crew exploration vehicle is, in fact, far more capability than is needed to go to and from the Space Station.

Because it serves a simpler mission, *any vehicle* that is designed simply to service the Space Station—and not go beyond—should be faster and more cost effective to develop without sacrificing safety, *regardless of whether it is a government or commercial capability*. The Gemini spacecraft, for example, was developed in just under 2 1/2 years, and had a perfect crew safety track record.

Regardless of the extent to which "the gap" can be reduced, a spacecraft designed solely for low Earth orbit transportation will be more cost effective to operate and require smaller launch vehicles. The result will be more frequent missions to the Station, increased research and other utilization of the Station, and more resources available for exploration beyond low Earth orbit.

Implementing a Commercial Crew Program

In light of all the considerations above, the Augustine Committee outlined a $2.5–3.0 billion fixed-price Commercial Crew program, in which NASA would invest in multiple private companies, each of which would also be required to invest their own funds, thereby putting their own "skin in the game." The committee also suggested that NASA fund human rating of a proven U.S. launch vehicle to mitigate the dependence on the development of new launch systems in addition to the spacecraft themselves.

A Commercial Crew program of $2.5–3.0 billion over 5 years should be sufficient funding. For example, one major aerospace company conducted a study that concluded they could develop a commercial capsule to transport crew to low Earth orbit and human rate an existing U.S. launch vehicle for around $1 billion. As another example, SpaceX has an unfunded option in its COTS Agreement for $308 million to upgrade its Dragon spacecraft to carry crew to and from the Station. Demonstrating the diversity of interest and capability, the Augustine Committee received price estimates from, according to the report, "five different companies interested in the provision of commercial crew transportation services to low-Earth orbit. These included large and small companies, some of which have previously developed crew systems for NASA."

Additional evidence that a Commercial Crew program is viable at $2.5–3.0 billion is again provided by the Gemini program. Despite only having access to 1960s technology, and with only a few years of total experience with spaceflight, NASA and industry human-rated the Titan II launch vehicle (which required 39 months), and designed and tested a crew capsule, for about $2.5 billion in today's dollars. The Gemini program completed all missions safely.

Since NASA's budget for the next five years is almost $95 billion, a $2.5 billion Commercial Crew program represents less than 3% of total NASA expenditures. Clearly, it is not an either/or proposition between commercial crew and NASA exploration. Commercial vehicles will not have the capability to go beyond low Earth orbit, while NASA must develop the capability to conduct exploration beyond low Earth orbit.

To promote competition and innovation, NASA's investment in a Commercial Crew program should be structured using milestone-based, fixed-price agreements as it is in the COTS program, unlike traditional cost-plus contracts. The COTS Cargo program has shown the wisdom in this approach. NASA initially selected two winners, SpaceX and Rocketplane-Kistler, rather than putting all of its eggs into one basket. When Rocketplane-Kistler failed to raise the capital to meet its milestones under its Space Act Agreement with NASA, NASA terminated its funding, held a new competition, and had 85 percent of the funding left over to give to the new winner, Orbital Sciences. This "portfolio approach" diversified the risk to NASA, greatly enhancing the likelihood that NASA will get the expected level of capability that it needs.

Safety of Commercial Human Spaceflight

Let me now address the safety of commercial human spaceflight systems. Safety is paramount. Private companies understand that they will not be in business if the systems they develop are not safe. In fact, private industry recognizes that it must increase safety from that demonstrated in the past in order to fulfill its vision of greatly increasing human activity in space. I believe industry has a healthy respect for the limits of their knowledge when it comes to safety. They do not presume to know it all and they maintain a strict discipline of safety. At the same time, they bring fresh eyes and insights from other cultures and I believe this will ultimately enhance safety.

Human spaceflight is an inherently risky endeavor. This has been true for government human spaceflight and will also be true for commercial. Working in partnership with NASA, U.S. industry firmly believes it can develop the capability to transport crew to low Earth orbit safely. Last month, 13 former NASA astronauts [1] endorsed commercial human spaceflight in a statement in the *Wall Street Journal*. This group of astronauts are highly experienced with spaceflight—collectively, they have flown a total 42 space missions and logged a total of 2 years and 48 days in space flying six different spacecraft including Gemini, Apollo, Space Shuttle, Soyuz, Mir, and the International Space Station. They stated:

> *"As astronauts, we know that safety is important. We are fully confident that the commercial spaceflight sector can provide a level of safety equal to that offered by the venerable Russian Soyuz system, which has flown safely for the last 38 years, and exceeding that of the Space Shuttle. Commercial transportation systems using boosters such as the Atlas V, Taurus II, or Falcon 9 will have the advantage of multiple unmanned flights to build a track record of safe operations prior to carrying humans. These vehicles are already set to fly over 40 flights to orbit in the next four years."*

Working together, NASA and the commercial industry *can* develop the capabilities to safely conduct human spaceflight. NASA and industry must begin the dialogue *now* on the requirements, standards, and processes necessary to make this successful for all involved. Agreement on the requirements is essential to the success of any partnership between NASA and the commercial sector.

There are several important factors to keep in mind when discussing the safety of commercial crew vehicles:

Commercial Spaceflight Has a Demonstrated Track Record

First, when we discuss commercial spaceflight, some tend to think of an activity in the future. In fact, commercial spaceflight occurs right now and has for years. Currently, the Atlas V and Delta IV launch vehicles—both commercially developed with substantial private funding—are used to launch multi-billion dollar national security payloads upon which the lives of our troops overseas depend. These vehicles are also entrusted by NASA to handle some of the most safety-critical applications in the civil space sector. For example, the Atlas V is Category 3 certified by NASA for launch of NASA's most critical payloads, and is also certified for launch of nuclear payloads, such as NASA's *New Horizons* spacecraft to Pluto, launched with radioactive plutonium onboard.

Not only is the commercial spaceflight sector real, but it has an extensive history of successful flights to orbit: the Atlas and Delta families of rockets, many of which were developed with substantial private investment and serve multiple customers, have a combined record of 114 consecutive successful flights since 2000. The Atlas V, for instance, has had 19 consecutive successful flights since its inception.

We must now turn our efforts to extending this demonstrated track record and depth of operational experience to human spaceflight. Fortunately, commercial human spaceflight to LEO will not require the development of new launch vehicles. Instead, it can be accomplished using existing launch vehicles and those currently under commercial development, such as the Atlas V, Falcon 9, and Taurus II launch vehicles. This will allow us to leverage our existing track record.

I will now examine some of the key requirements for ensuring the safety of commercial spaceflight, and explain how the commercial spaceflight sector can meet these high standards.

Key Requirements for Commercial Spaceflight Safety

Since computer calculations of vehicle safety cannot account for most of the root causes of accidents historically, such as human error or design flaws, and since even reliable vehicles have historically suffered a period of "infant mortality," the commercial spaceflight industry believes that safety must include the following:

- Demonstrated reliability from orbital flight tests of the full system
- Not placing crews on initial flights, since early flights are historically most risky
- A highly reliable crew escape system
- Standards-driven design and operations

[1] The astronaut signatories were Buzz Aldrin, Ken Bowersox, Jake Garn, Robert Gibson, Hank Hartsfield, John Herrington, Byron Lichtenberg, John Lounge, Rick Searfoss, Norman Thagard, Kathryn Thornton, Jim Voss and Charles Walker.

I will now consider each of these topics in turn.

I. Demonstrated Reliability from Orbital Flight Tests: By the time any astronaut climbs onboard a commercial vehicle, including the Atlas V, Falcon 9, and Taurus 2, each will have had multiple demonstrated successful flights to orbit. For example, SpaceX's Falcon 9 would likely have more than 15 missions prior to its first crewed launch, due to customers such as the COTS Cargo program and satellite launches. As the *Wall Street Journal* astronauts pointed out, the Atlas, Falcon, Delta, and Taurus systems combined have over 40 more missions on the manifest before 2014, in addition to numerous flights of commercial systems that have taken place before this year.

Human-rating of existing launch systems will cost money, and care must be taken, but as a recent study by The Aerospace Corporation concluded, there are no show-stoppers to human rating the existing proven fleet of launch vehicles. Norm Augustine pointed out that we did it safely for Mercury and Gemini, when our expertise in human spaceflight was much lower than it is today, and we can do it now.

Demonstrated reliability is so important because computer models and Probabilistic Risk Assessments (PRAs) are not sufficient to capture the majority of failure modes that affect real, flying vehicles—especially vehicles that are flying their first few missions. The Augustine Committee, which included two experienced astronauts, pointed out the following on PRAs:

> *"Studies of risk associated with different launch vehicles (both human-rated and non-human-rated) reveal that many accidents are a result of poor processes, process lapses, human error, or design flaws. Very few result from so-called random component failures. The often-used Probabilistic Risk Assessment (PRA) is a measure of a launch vehicle's susceptibility to these component or system failures. It provides a useful way to compare the relative risks of mature launch vehicles (in which the design is well understood and processes are in place); it is not as useful a guide as to whether a new launch vehicle will fail during operations, especially during its early flights."*

Probabilistic Risk Assessments and computer models are useful tools, but they have limitations. While the commercial spaceflight industry will make use of every tool that is available to improve safety, computer models are just one tool among many. Demonstrated reliability and a robust flight test program are crucial. Reasonable minds can differ on *how many* successful launches is sufficient before putting people on top, but there is no debate that *more is better*.

At this point, let me briefly address two myths surrounding the safety of commercially procured crew transportation systems. First, some have claimed that commercial crew systems will only be able to produce cost savings for NASA by cutting corners and being less safe. In fact, commercial crew systems are cheaper for a different reason—because they have a less ambitious mission than systems designed for exploration. Since commercial LEO systems are simply tackling a less difficult challenge, commercial crew will be able to achieve cost savings for Space Station missions without cutting any safety corners. By focusing on a less ambitious mission that requires less capable vehicle performance, the commercial spaceflight industry is following a statement of the Columbia Accident Investigation Board that "the design of the system should give overriding priority to crew safety, rather than trade safety against other performance criteria."

Second, some have claimed that NASA's Exploration Systems Architecture Study (ESAS) shows that the current exploration vehicles are safer than commercial crew vehicles. In actuality, commercial crew vehicles were never even analyzed in the ESAS report—the ESAS report only looked at vehicles large enough to carry Orion, such as Ares I and variants of the triple-core Delta IV Heavy, and did not examine the smaller, simple, single-core vehicles, such as Atlas V Medium and Falcon 9 Medium that are sufficiently sized for commercial crew missions. Moreover, even if ESAS had compared exploration vehicles to commercial crew-sized vehicles, the comparisons would be "apples vs. oranges," because of the dramatically different tasks of these two types of vehicles.

II. Not Risking Crew During Initial Flight Tests: Historical records show that even reliable vehicles, such as the Soyuz, initially go through a period of lower reliability ("infant mortality") as design flaws are caught and corrected. The use of proven launch vehicles enhances safety by using a mature system with a demonstrated track record that has gone through the infant mortality stage experienced by most new launch systems.

By leveraging the cargo and satellite flights, such as the COTS Cargo flights, that precede the first crewed flights, the commercial sector can help ensure that the infant mortality phase does not risk human lives. Commercial providers are free to pursue multiple customers, such as NASA science missions, national security missions, or commercial satellite missions, to help extend and strengthen the crucial test flight phase before humans are launched. Again, reasonable minds can differ on how many test flights are needed in light of infant mortality, but all can agree that it is good that the commercial sector can leverage non-crewed flights, such as cargo and satellite launches, to help alleviate crew risks associated with flying during the infant mortality phase.

III. A Robust Crew Escape System: In addition to demonstrated reliability of the launch vehicle, ascent safety will be based on an *emergency detection system* to detect any anomalies during launch and a *crew escape system* to separate the spacecraft from the launch vehicle in the event of an anomaly.

The commercial spaceflight industry understands that safety requires not just a reliable launch vehicle, but an integrated system with robust crew escape capabilities. As the Augustine Committee notes, "It is unquestionable that crews need access to low-Earth orbit at significantly lower risk than the Shuttle provides. The best architecture to assure such safe access would be the combination of a high reliability rocket and . . . a launch escape system." The commercial spaceflight industry is committed to meeting this combination.

IV. Effective Government Oversight: Human spaceflight is now almost 50 years old with the first flights of Alan Shepard and John Glenn occurring before I was born. It is time to transition access to low Earth orbit to the private sector so NASA can once again lead exploration beyond. Nevertheless, NASA and the FAA will be involved in every step of a Commercial Crew Program. In fact, every human spacecraft to date has been developed in partnership between NASA and U.S. industry, and this will also be true for a Commercial Crew Program. I will now address this crucial topic in more detail.

First, any NASA Commercial Crew Program must be conducted under the current regulatory regime established by law, namely, licensing by the Federal Aviation Administration (FAA) Office of Commercial Space Transportation. FAA licensing of commercial spaceflight activities is established by law, requires a high degree of system safety, and provides a stable and predictable regulatory environment necessary for the success of commercial human spaceflight businesses. As codified in existing U.S. law, a licensing regime, rather than a certification regime, is appropriate for these vehicles.

While the FAA would retain overall licensing approval authority, NASA would maintain strong oversight as the mission customer. As with today's commercial expendable launches, the customer has go/no-go authority over the readiness of the mission and, therefore, NASA would maintain its role as safety approval authority for its crew onboard any commercial vehicle. NASA-unique requirements would be imposed as customer requirements, rather than as the overall regulator of the commercial spaceflight activity. (This is discussed in more detail in the next section.)

While it is appropriate for NASA to establish customer-specific requirements, an entirely new licensing or regulatory regime, separate from the current FAA regime, should not be established for NASA or any other entity that would require compliance with different rules and regulations for commercial human spaceflight services provided for U.S. Government and commercial customers. The creation of a NASA-specific regulatory regime would impose parallel regulatory and operating environments for commercial operations for private customers and "commercial" operations for NASA. A two-track regulatory environment could hurt industry's ability to obtain non-NASA customers, impacting business viability by lowering the total number of flights. Such a situation would be the opposite of the more robust flight history and greater operational experience that is crucial to enhance safety.

NASA Will Be There Every Step of the Way

In any Commercial Crew program, NASA will play a pivotal role in the design, development, and operation of the commercial vehicles. NASA will be there every step of the way. In particular:

- NASA, in consultation with industry, will establish baseline human spaceflight safety requirements. That dialogue must begin now.
- NASA will also establish its mission-unique requirements, such as crew capacity; ability to dock with the International Space Station, including meeting visiting vehicle requirements; and functionality as a crew rescue vehicle, among others.
- And NASA will have final approval authority over the launch of NASA astronauts on commercial vehicles, which would be granted *only after being satisfied* that the vehicle is safe for launch, just as it does for today's Space Shuttle missions.

Whether or not these safety requirements are the same as those found in NASA's current human-rating requirements document (NPR 8705.2B) is currently under consideration. NASA is reviewing its human-rating requirements as they would be applied to commercial human spaceflight capabilities. This is the right thing for NASA to do and I applaud them for doing so.

In fact, there is already a precedent for reviewing human-rating requirements. During the Constellation Program, NASA revised its human-rating requirements document in May 2008, going from the original version A to the current version B. Based on the judgment of NASA engineers, version B revised some requirements related to structural safety margins and dual-fault tolerance. In fact, no existing U.S. spacecraft—or Russian, for that matter—has ever met all of NASA's human-rating requirements, but rather have obtained waivers to certain requirements. These examples demonstrate the importance of early dialogue between NASA and the commercial spaceflight sector on the nature of human-rating requirements for commercial systems, with demonstrated reliability, robust test flights, and a reliable crew escape system being key.

While NASA is conducting its review, U.S. industry is also conducting a similar review. We have established a Commercial Orbital Human Spaceflight Safety Working Group. While the Commercial Spaceflight Federation has taken the lead in organizing the effort, the working group includes representatives from a broader spectrum of companies, including several of the major aerospace primes and more traditional government space contractors. The goal of the effort is to develop industry consensus on principles for safety of commercial orbital human spaceflight. So far, we have met among industry and have begun to engage NASA and the FAA. There is much more work to be done. However, consensus has been reached among a number of companies on principles with other companies currently reviewing the document. Regardless, it has already been useful in illuminating the issues and differing perspectives of those involved and is an important step in the right direction.

Finally, I note that industry and NASA standards will include more than just the launch vehicle. For example, once in orbit, spacecraft must rendezvous with the Space Station, dock or berth with it, and then undock and de-orbit, reentering the atmosphere and landing safely back on Earth. The technologies to rendezvous and dock with the Station have been demonstrated by the United States, Russia, Europe and Japan. Working in partnership with NASA, Europe and Japan demonstrated these capabilities this year, and NASA is working with SpaceX and Orbital Sciences here at home to demonstrate the same capabilities under the COTS Cargo program. Examples such as these illustrate the importance of cooperation between the private sector and NASA to ensure safe operations.

Conclusion: A Partnership Between NASA and U.S. Industry

The discussion of standards brings me to one of the most important prerequisites for success of any Commercial Crew Program—*how* NASA engages with the private sector is ultimately as important, if not more important, than the amount of funding provided. NASA's COTS Cargo program is an excellent example. While some were initially resistant to commercial resupply of the Station, once it became a necessity NASA engaged the private sector in true partnership in order to ensure that the capability is available as soon as possible.

I have every confidence that we are at such a turning point with Commercial Crew as well. It is now a necessity, and I believe that NASA and industry will *both step up* to make it happen.

Thank you for the opportunity to be here today and I look forward to your questions.

Chairwoman GIFFORDS. Thank you, Mr. Alexander.

Dr. Fragola.

STATEMENT OF JOSEPH FRAGOLA, VICE PRESIDENT, VALADOR, INC.

Mr. FRAGOLA. Madam Chairwoman and distinguished members, it is an honor to be able to be before you today, and I would like to share with you some of the experience that I have had in the form of four simple laws for a safe space launcher design.

The first law has been referred to before, and that is to make the design as inherently safe as possible. That involves two important aspects: first, to make the launcher reliable, and second, and this is four times not mentioned in discussion, to make sure that the failure modes of the launch vehicle present a benign environment to the abort system. This is so important I would like to repeat it: to assess the vehicle to make sure that the abort modes given a failure represent a benign environment for the system for escape. Second, separate the crew from the source of failure as far as possible in the design, or as I like to say, put them on top where God meant them to be. Third, establish a credible abort trigger set, and in doing so, balancing the warning time available with the threat of false positives against the G load on the crew. Fourth, include an abort system that is tested and verified for robustness to allow for a safe crew escape and recovery.

I would mention that from my experience, the Ares I vehicle is the singular vehicle that has been designed from the very moment of its conception with safety in mind. What I mean by that is that other launches, for example, have emphasized launch reliability but investigation of subsequent two accident conditions allowing for abort is something they usually don't address, and the reason for it is very simple. They are interested primarily in payload to orbit. When a payload fails, the subsequent conditions are no matter to the person who pays for the payload. When a crew launcher fails, the conditions subsequent to that launch failure are important to the payload, which is the crew.

We hope that the alternatives to the Ares I will follow the remainder of the rules that we mentioned, but in most of the literature discussing it, the importance of an abort system and the testing of an abort system independent of the number of experiences of the launcher has not really been addressed. Many times, for example, we speak of successes in terms of maybe 19 successes of the Atlas V, which is a credible, wonderful, reliable record but I will remind the Subcommittee that the space shuttle had 25 successes prior to the *Challenger* accident.

One of the things to remember in the design of a new launch vehicle or the application of an existing launch vehicle to crew is to understand that invariably in modifications of designs or the development of new designs we have an issue of reliability growth. Immature designs need time to become mature, and that is why the abort system testing and integration into the design and the benign nature of the failure initiators is extremely important for a crewed launcher.

Now, as was mentioned, we did an independent assessment of the Ares on an apples-to-apples comparative basis to all the other alternatives we were provided, and I showed this on a slide that is presented there. On a comparative basis, you can see that from the standpoint of loss of crew, the Ares vehicle is somewhere between two to three times safer than all the alternatives, in some cases more than three times safer than the alternative vehicles. If we look at this, people often mention yes, but there is a certain amount of uncertainty, there certainly is uncertainty but even with the uncertainty taken into consideration, the loss of crew benefits from the Ares I vehicle are significant above the alternatives. The reason for it is not only its inherent reliability in the first stage proven in 255 successful shuttle launches but also the nature of a solid rocket booster. The predominant failure mode by far is case breach, nozzle burn-through or joint burn-through. All of those alternatives, although they are very significant when combined with a single core liquid or a tandem booster in a singular solid rocket booster present a rather benign abort environment to launch abort system. It is the combination of this inherent reliability and its inherent benign abort conditions that make the Ares I such a safe launcher and that is the reason why it was designed from the beginning in that way. Thank you.

[The prepared statement of Mr. Fragola follows:]

PREPARED STATEMENT OF JOSEPH R. FRAGOLA

Madam Chairwoman, distinguished members of the Subcommittee: I want to thank you for the opportunity to address you today. My testimony will detail my personal perspective on the ongoing focus on safety matters with regard to human space flight, focusing primarily on how NASA sought to better safety ratios for the Constellation Program via a risk-informed design process whose overriding priority has always been and will always be crew safety.

Introduction

> ***Risk-based Design for Inherently Safe Crewed Launchers****: The design of the system [that replaces the shuttle] should give overriding priority to crew safety, than trade safety against other performance criteria, such as low cost and reusability, or against advanced space operation capabilities other than crew transfer. (Columbia Accident Investigation Board (CAIB) Report Section 9.3)*

This quote from the CAIB gives NASA clear direction to the design of the next generation crew launch system: make it simple, make it safe, and let the driving design principle be crew safety. That is simple enough to say, but how do we design for safety from the start? In other words, how do we make it "inherently safe" while also protecting against residual risk, in a mass-constrained, highly-energetic system such as a launch vehicle? To paraphrase the definition of inherently safe design is to say that the principle objective of the design process should be to eliminate, or at least reduce to a minimum, the hazards associated with the process so that the elimination or reduction is both permanent and inseparable from the design. Once a design concept has eliminated or reduced the hazards to a minimum, the designers can focus on developing acceptable mitigation approaches for the residual risks. This process is referred to as a risk-based or risk-informed design.

NASA has utilized the May 2004 memo from the Chief of the Astronaut Office on future system launch safety as guidance in designing for ascent safety. A key statement from this memo is,

> *The Astronaut Office believes that an order-of-magnitude reduction in the risk of loss of human life during ascent, compared to the Space Shuttle, is both achievable with current technology and consistent with NASA's focus on steadily improving rocket reliability, and should therefore represent a minimum safety benchmark for future systems. This corresponds to a predicted ascent reliability of at least 0.999. To ensure that a new system will achieve or surpass its safety requirement, it should be designed and tested to do so with a statistical confidence level of 95%. (Astronaut Office Memo)*

The paragraphs that follow explain how this is being accomplished in the development of what has come to be the Ares I crew launcher and Orion spacecraft, and why the current design is believed to be inherently safer and operationally safer than alternative design concepts that might be equal in operational capability, or in some cases even more capable. The Constellation system is the only launch system that has been specifically engineered to meet the Crew Office memorandum guidance of 1 in 1,000 missions loss of crew (LOC).

The Two Elements of Risk-Informed Design

In the Apollo era, crewed launchers were fundamentally designed with the best level of expertise available, tested to exhaustion, and then robustness or redundancy was added to mitigate the residual risk. This redundancy was applied across the design and included engine-out capability during at least portions of ascent, launch escape capability, a "life boat" vehicle on the way to the Moon, an abort stage possibility during descent to the lunar surface, and component robustness or redundancy where element redundancy was no longer possible. Reliability and risk-informing analyses were primarily qualitative, such as Failure Modes and Effects Analyses (FMEAs), which were applied as a check of the design rather than being integral to the design development.

Design development for Constellation, therefore, has consisted of two key tenets related to safety. These are to make the design as reliable as possible (inherent safety), so that backup systems would never have to be used, and to make the backup systems as robust as possible to maximize the likelihood of crew survival and return given a failure of the primary system or element. Notice that, in the Apollo era, redundancy or robustness was not added for mission continuance as it was in the shuttle era in some cases at least, but was applied to ensure safe return of the crew.

Tenet Number 1—Make the Design Inherently Safe

As codified in Constellation Program safety policy, inherent safety implies the elimination of hazards that have historically been associated with the operation of the type of system being designed. This in turn implies the systematic identification of the hazards associated with operation of the system alternatives being considered. The process of hazard identification is implemented in a global sense by a hazard analysis, which essentially establishes the potential spectrum of generic hazards that might be applicable to a particular design. The hazard analysis also establishes a local evaluation of the credibility of these hazards being applicable to the design in terms of their likelihood of being activated, as well as the local conditions that would determine their consequences if unmitigated. Both the *likelihood of activation* and the *associated consequences* once activated are established and developed from historical data on heritage systems and the combined judgment of design and safety experts on how this heritage data applies to each specific design alternative.

If mission reliability, i.e., inherent safety, were equivalent to crew safety as it is for payload "safety," then the task that would be left to the analysts would be to inform the decision makers of the forecasted mission reliability of each design. Even in this case, an alternative that employed a first stage that made use of a solid, which could subsume the reliability of the shuttle solid, would be a strong contender because the shuttle solid has demonstrated a mission reliability of just a single failure in approximately 250+ booster firings. This implied demonstrated reliability of 0.996, or 99.6%, rivals the best of the best of the boosters worldwide. However, in the case of crew safety, mission reliability is not the entire story.

Tenet Number 2—Adequacy of "Abort Effectiveness"

The shuttle designers, unlike the Apollo designers before them, concentrated fully and completely on the inherent safety of the vehicle—that is, they relied on the forecasted mission reliability of the design alone to guarantee crew safety. Clearly, the primary focus of a launcher design should be on mission reliability, regardless of whether or not it is crewed. The primary objective of the design should always be to avoid failure.

A mitigating system, given a failure, should never be used as a crutch to enhance crew safety, but rather only be used as a way to abort the mission and recover the crew. However, unless the reliability of the primary design can be assured to a significantly high degree, a mitigating system (such as the Orion Launch Abort System) is essential to ensuring crew safety. The crew safety enhancing power of an abort system is generated by the fact that it provides an additional or conditional crew survival probability given the occurrence of a crew threatening event. This conditional probability of a successful abort and return given a crew-threatening event is referred to as the "Abort Effectiveness."

The abort effectiveness value is a function of several things: the probability that the abort can be initiated in time to allow for a safe distance to be established for crew survival with employing an acceleration that also allows for survival, the reliability of the abort system, and the conditions that the crew vehicle will be obligated to negotiate subsequent to the abort initiation. In the days of Apollo, when NASA had comparatively little experience and computational capability, the abort effectiveness was estimated by comparison to escapes from high-performance military aircraft combined with the results of a few escape system tests, Little Joe I and II.

Today, Constellation is systematically applying throughout the design process the software simulation tools and advanced computers that allow us to do a much better analytic design assessment than Apollo. Specifically, the integrated abort effectiveness can now be calculated by employing more realistic simulations of abort conditions. The integrated abort effectiveness is the effectiveness of each abort against each initiated abort scenario weighted by the occurrence probability of the scenario.

While simulation tools and computational capability were unavailable in the Apollo era, today this calculation can be carried out with reasonable accuracy.

The value of the abort effectiveness for each acceptable, payload-capable alternative is possible but complicated to determine. However, what is known is that the primary determinate of the effectiveness of an abort is the time available to affect the abort along with the severity and extent of the environment in the abort locale.

Top Level Risk-Informed Design Selection During ESAS

The above paragraphs have indicated the importance of incorporating risk evaluation from the very beginning of the crewed launcher design selection process to achieve an overriding priority for crew safety. Without this focus on safety risk evaluation, the crew launcher focus can slip into one emphasizing performance over safety. Even with safety as the overriding priority, the launcher must have acceptable payload capability and be affordable. Safety risk alone cannot be the criteria for the selection of a crew launcher design. Decisions must be made with safety risk as a priority, but within the context of a risk, performance, and cost picture. This implies that from a top-down perspective, potential crewed launchers should be each evaluated on the basis of cost, performance, and risk simultaneously, and this is just how the ESAS study efforts for the selection of a crewed launcher design proceeded.

During ESAS, any launch vehicle concept that did not approach at least 1 in 1,000 forecasted launch Loss of Crew (LOC) risk was eliminated. In addition, concepts that would place the crew module in close proximity to the boosters and/or other potential sources of accident initiation were eliminated because it as anticipated they would interfere in NASA's ability to incorporate a launch abort system into the next-generation launch vehicles. Lastly, as part of its findings, the ESAS team recommended that this risk-informed design process be extended to the development of the design of the selected single solid First Stage concept, which would later be known as the Ares 1 Crew Launch Vehicle.

Constellation Safety Story

The Constellation program baseline was derived directly from the ESAS recommendations, and a clear discriminator among crew launch vehicle alternatives was the relative complexity of the launcher's first stage and the effectiveness of the crew escape system.

The Ares I first stage (FS) consists of a 5-segment reusable solid rocket motor (RSRM), an aft skirt, a forward skirt, and a frustum. The 5-segment solid is an evolutionary growth from the 4-segment solid RSRM tandem boosters utilized to power the space shuttle. The Ares I booster will continue the protocol of recovery and post-flight inspection that began in the Shuttle Program. To summarize, the 5-segment solid for the Ares I has many advantages over other designs, including:

- Drawing extensively from the heritage and knowledge derived from the Shuttle RSRM Program. There have been 252 solids flown in the Shuttle Program with one failure (Challenger STS–51L).
- Applying the knowledge gained from that experience-base to actively improve design features.
- Utilizing extensive qualification and flight test programs.
- Incorporating a failure-tolerant design against the primary failure modes of joint leakage and case burn-through.
- Incorporating an extensive system of process controls in manufacturing and assembly.
- Benefiting from the basic Ares "single-stick" architecture, which eliminates the possibility of engaging elements that are radially or tandem mounted.

The Orion crew capsule will have a Launch Abort System (LAS) that will offer a safe, reliable method of moving the entire crew out of danger in the event of an emergency on the launch pad or during entire first stage and the most risk intense portion of the second stage climb to Earth orbit. Mounted at the top of the Orion and Ares I launch vehicle stack, the abort system will be capable of automatically separating the Orion from the launch vehicle and positioning the Orion and its crew for a safe landing. NASA plans a series of tests to characterize the LAS. Pad Abort (PA)-1, which is planned for March 2010, is the first of these tests and will address what happens if an emergency occurs while the Orion and the launch vehicle are still on the launch pad. Other such tests will determine how the LAS behaves during critical parts of the flight regime. These tests will take place at White Sands Missile Range, New Mexico.

NASA is making substantial progress in maturing its approach and design methodology for designing a robust crew-launch system. From the very onset of the Constellation Program, the NASA design team insisted on the application of a risk-informed design approach. That is, safety risk members are included as integral parts of the Constellation design team. They are chartered to develop risk-informed approaches for the Ares I and Orion design concept refinement, and are included in all trade studies that involved safety risk.

The skill mix of the NASA team includes not only the Failure Modes and Effects Analyses, Integrated Hazard, and Probabilistic Risk Assessment (PRA) disciplines traditionally found under the Safety and Mission Assurance (S&MA) organizations, but also engineers with such backgrounds as computational fluid dynamics (CFD), Aerospace, and Physics disciplines. The team functions as a single group entitled Crew Safety and Reliability (CSR) and has been given the clear direction to work daily with the design engineers to provide expertise and feedback via various assessments and analysis techniques throughout the design maturation process. This investment continuously emphasizes a sincere commitment to the CAIB findings.

Additionally, the primary modus operandi of past programs has been to provide intermittent reviews of design "drops" at the prescribed reviews. This limited meaningful insight into the systems development, which was occurring in the everyday work environment where design risks, nuances, trade studies, etc., are introduced. The Constellation approach, by contrast, has fostered the development of a truly risk-informed culture on a continuing and synergistic basis.

In parallel and in concert with the Ares I design development; NASA's Constellation team is providing the resources for the development of the supporting logical and phenomenological (or physics-based) computer models and associated historical data sets. This allows for the identification of all credible potential events that might initiate an accident, the extant local external environmental conditions as determined by aero-physics computer models, and internal conditions, as determined initially by judgment and then later by motor and engine physics computer models, at the postulated time in the ascent trajectory that initiator was to occur. Then the global environment is imposed upon the integrated ascending Ares I stack and on the Orion crew module as determined by sophisticated computer models replicating those environments seen as potentially assaulting the vulnerabilities of Orion. Specifically, fragmentation fields, propagated impulse and pressure fields, and thermal radiation fields generated by the accident scenarios are initiated, forming the basis of the 'blast environment' that the Orion must escape from.

Currently the Ares I has an estimated AE of about 84%, which when combined with its high heritage based inherent reliability makes it two to three times safer than alternative launchers as shown in Table 1 and in graphical form in Figure 1. This corresponds to a LOM of 1 in 200 in ascent, which leads to LOC of about 1 in 1300 according to our independent calculations.

Table 1 - Relative LOC LOM Results of an Independent Assessment

	LOSS OF MISSION		LOSS OF CREW	
	Mean	5%-95% interval	Mean	5%-95% interval
Ares I*	1	1	1	1
Ares V	2.5	1.6 - 3.5	2.7	1.6 - 4.3
Side Mount	1.9	1.2 - 2.9	3.6	1.6 - 6.8
EELV-3.2**	2.6	1.9 - 3.9	2.9	2.0 - 4.4
EELV-4.1-100%	2.5	1.6 - 3.8	2.4	1.4 - 4.1
EELV-4.1-75%	2.1	1.4 - 3.3	2.5	1.6 - 4.0
EELV-J2X	1.8	1.0 - 3.1	2.0	1.1 - 3.3

*no error bar on the Ares I number: we know with certainty that the risk of Ares I is equal to the risk of Ares I, whatever its absolute level

**vehicle does not meet the performance requirements; included for comparative purposes only

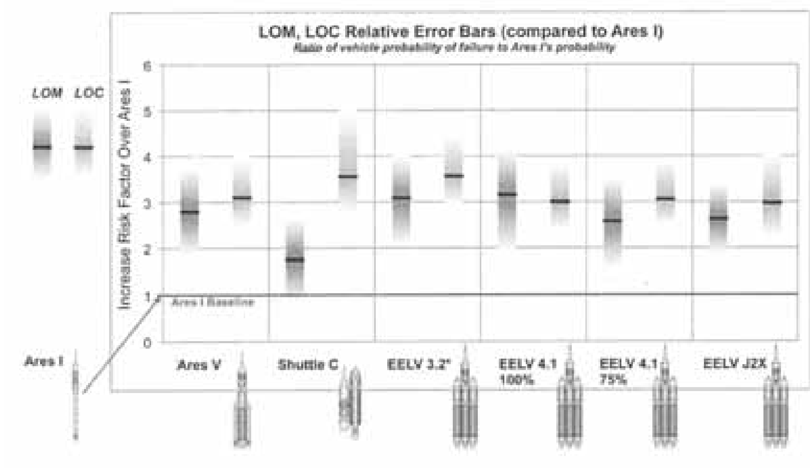

Figure 1 - Relative Results of an Independent LOC LOM Assessment

Meanwhile, examples of cases where the risk assessment and failure analysis teams have provided input and/or impacted the outcome of Constellation design issues, trades, or risks include the following.

- Abort triggers study: Provided LOC and Abort Effectiveness assessments, including engineering models and timing, to determine what potentially catastrophic scenarios warrant abort sensors and software algorithms.
- Separation study (booster deceleration motors (BDMs)): Hazard analysis combined with probabilistic design analysis (PDA) led to the design decision to increase the number of BDMs from 8 to 10.
- The Hazards Team identified that the first stage and upper stage designs failed to meet properly at the interface flange (different number of bolts) and a re-design was instituted. Hazards team provided assessment to Upper Stage that resulted in clocking of the hydrogen and oxygen vents to improve separation distance.
- Orion and Ares systems architecture trades: risk assessment and failure analysis teams have informed the active mitigation of systems design vulnerabilities for both the rocket and spacecraft.
- Failure Modes and Effects Analysis teams:
    - J–2X FMEA was used to support redline sensor selection in order to detect failure modes prior to their propagation to a catastrophic condition.
    - Upper Stage Main Propulsion System (MPS) FMEA identified need for modifications related to solenoid valves to increase reliability and failure mitigation.
    - US Reaction Control System FMEA identified need for additional temperature sensors to detect freezing of hydrazine to support launch commit criteria.
    - US Flight Safety System (FSS) FMEA identified need to relocate cryogenic helium line that was adjacent to Flight Termination System (FTS) linear shaped charge.
    - FS Roll Control System was changed from bipropellant to monopropellant due to significant reduction in critical failure modes.

Summary

The Constellation design development process has, and continues to employ, a continuous risk-informed design process adopted from the outset of the program. This process has included both logical and physical simulation models as appropriate in a way that has had a synergistically beneficial impact on Orion and Ares I designs by allowing them to be developed with an "overriding priority" given to crew safety at every stage of the design and operational processes. I believe that the Constellation development represents a successful, pioneering application of a new approach to engineering design, a type of engineering risk design, which will have multiple applications and refinements in aerospace system designs in the future.

Closing

In closing, I would be remiss if 1 did not bring your attention to a statement from the Augustine report that I believe to be problematic. Specifically, on page 9 of their report the Committee states:

> *Can we explore with reasonable assurances of human safety? Human space travel has many benefits, but it is an inherently dangerous endeavor. Human safety can never be absolutely assured, but throughout this report, safety is treated as a* sine qua non. *It is not discussed in extensive detail because any concepts falling short in human safety have simply been eliminated from consideration. (Augustine 9)*

I believe this statement to be problematic because I believe it to be indicative of what I like to call a "goal post" mentality rather than the proper safety mentality which should be "As low as reasonably achievable", or ALARA. In the former case items are considered safe if they meet the criterion, in this case "human safety", or not if they don't. If they meet the criterion and are considered safe they are retained, and if they don't they are considered unsafe and are eliminated from consideration. It matters not if some alternatives just miss the criterion, or they miss it by a mile, they are eliminated nonetheless. And if they just make the criterion or they are much better, they are all considered "safe". While it is certainly true that safety cannot be assured in spaceflight and it is also true that the safety level of concepts are uncertain this approach has led in the past in other industries, such as the commercial nuclear power industry, to a safety perspective that focused only on which concepts or designs should be considered safe and which not. In this way the safety bar is set to include the lowest acceptable rather than focusing on which designs were as safe as achievable. There are always uncertainties in every analysis, and risk analysis is no exception. Still when solid, heritage-based analysis shows significant differences in safety risk amongst alternatives it is questionable how an investigation that claims safety as a *sine qua non* can fail to highlight these discriminations.

Now it is true that the goal post approach will eliminate design concepts that are clearly unacceptable, but it also fails to discriminate designs that are clearly desirable among those that are acceptably safe. It is my belief that the Ares I vehicle, because of its inherent focus on being as safe as achievable from the very start, has the best chance to be an outstandingly safe crew launcher. There is no way to insure safety, and spaceflight will always be a risky endeavor, but a launcher that is designed to be safe from the start, at least to me, is a good way to begin.

Madam Chairwoman, I would like to thank you and the members of this Subcommittee for the opportunity to express my ideas. I would be pleased to respond to any questions that you or the other Members may have.

Chairwoman GIFFORDS. Thank you, Dr. Fragola.

General Stafford.

STATEMENT OF LT. GEN. (RET.) THOMAS STAFFORD, UNITED STATES AIR FORCE

Lt. Gen. STAFFORD. Chairwoman Giffords, Ranking Member Olson, distinguished members of the Committee, many old friends, I am honored to be invited here to appear before you today to testify on the matter of crew safety in human spaceflight.

As a result of the Augustine Committee report, it is imperative that the information and their observations that resulted in recommendations be considered carefully before the Congress directs or allows changes to be made to the program that NASA has pursued and the Congress has approved over the past years. Mr. Augustine invited me to be the first presenter to the committee due to the fact that I presently chair the ISS Independent Advisory Taskforce and previously had chaired the Shuttle-Mir Taskforce. I had also chaired a yearlong study at the direction of the Vice President on how NASA should return to the moon and go on to Mars in a safer, better and a more rapid timeframe at a minimum cost. The study was titled "America at the Threshold" and Mr. Augustine provided a copy to all members of the committee prior to that first meeting they had.

After the *Columbia* accident in 2003, I was asked by the NASA Administrator to chair the Return to Flight Task Group to review the Columbia Accident Investigation Board recommendations to ensure that these recommendations are carried out by NASA before the space shuttle return to light, and today I want to acknowledge the work performed by the Augustine Commission that covered these broad-based subjects in a relatively short period of time. After my own extensive examination of the committee's reports, I strongly agree with the majority of their findings. However, on a few I disagree.

I would strongly agree that the NASA Administrator who is assigned responsibility for the management of NASA needs to be given authority to manage the agency. This includes restructuring resources, the workforce and facilities to meet the needs. The Augustine committee has pointed out to some of the underlying concerns and all the deliberations on the future of U.S. human spaceflight program are that NASA has been inadequately funded for many years, and on this point I strongly agree. I certainly hope that this year a satisfactory appropriations bill for NASA will be passed.

I agree with the committee's recommendation that the remaining space shuttle flights should be launched on a schedule that is compatible with the normal procedures that are used for safe checkout and test for launch operations and which may extend to flights into 2011. We presently have a shuttle at KSC standby on notice for rescue if required. If funding were available, this shuttle should launch large cargo that could enhance the viability of the ISS six-person crew capability.

The committee wisely recommended the continuation of U.S. participation in the ISS to be extended to 2020. We must remember that the United States cannot make a unilateral decision to end and deorbit the International Space Station. However, the ISS will never be fully and effectively utilized unless researchers and all the ISS international partners have confidence that the facility will be supported and sustained as long as it is operationally viable and technically useful. To effectively use this great international laboratory, the ISS requires a guaranteed cargo and crew delivery to be available as soon as possible after the space shuttle retirement. Yet the committee suggested that the responsibility be removed from NASA and offered to commercial contractors. It is feasible for the U.S. industry to develop a commercial cargo crew delivery system to the ISS. However, the cargo dimensions are somewhat limited.

The commercial transport of government crews to the ISS has major implications of which I have a very different view. I would like to differentiate the two subjects: potential commercial crew cargo delivery to the ISS and commercial crew delivery to the ISS. NASA has incentivized and selected two contractors to provide commercial cargo delivery to the ISS, and for commercial cargo delivery, the first issue is development of a reliable booster to low earth orbit. The second issue is to develop an autonomous transfer vehicle to transfer the cargo from the booster to the ISS in a safe manner that would meet the ISS visiting spacecraft requirements, which were recently complied with by the European Space Agency's ATV and the Japanese HTV.

The development of a transfer vehicle is in itself a significant challenge. The European Space Agency recently delivered their first ATV payload approximately four years later than their initial target delivery date. The Japanese delivered their HTV some two years later than their initial target date. Both government entities used considerable resources to develop these individual transfer vehicles. I certainly wish the two U.S. entities success in meeting their NASA milestones for cargo delivery since the ISS is dependent upon continued supply of cargo delivery by the partners.

With respect to commercial government crew launch delivery to the ISS, I would like to recall my own experience. I flew on two Gemini missions with a specially modified Titan II ICBM booster and two Apollo missions, one on the small Saturn IB and one on a giant Saturn V, and over the period of 13 years I experienced and participated in development of high reliability, human-rated boosters, human-rated spacecraft and launch abort systems. I was the backup pilot for the first manned Gemini flight and spent many months in the factory and countless hours in the spacecraft as it was being built and tested. I was then pilot of Gemini VI, the world's first rendezvous mission, and on that the Titan II stage ignited and then shut down at T0. Wally Schira and I had the liftoff signals in the spacecraft and a fire broke out down below the base of the booster. The special emergency detection system that had been installed on that Titan II helped us resolve a couple of critical failures and our own decisions prevented a fatality. Had that not been modified and the decisions right, I would not be here today, Madam Chairman, and you would have been reading about me in the obituary column.

I was also backup commander for the second Block I Apollo flight and had my crew performing a similar test in the sister spacecraft at the same time the Apollo I accident occurred and the Apollo I crew died in the fire at the Cape. I was a backup commander on the first Apollo Block II spacecraft, Apollo VII, and again spent considerable time in the factory as it was undergoing tests and fabrication. At that time there were numerous NASA engineers, inspectors, support technicians to facilitate this effort.

I was then commander of Apollo X, the first flight of the lunar module to the Moon and again I spent an inordinate amount of time in performing the tests to check out the command and the lunar module.

My fourth mission was commander of the Apollo-Soyuz Test Program. Again, I spent considerable time in that spacecraft and also a brief time in the Soyuz spacecraft for the first flew we ever flew. These flights both as prime and backup crew members were accompanied by thousands of hours of training in different types of spacecraft simulators and mockups in which numerous emergency situations were simulated and resolved. Therefore, safe delivery of a government crew to the ISS involves the human rating of a launch vehicle, the spacecraft, the launch abort system, successful integration of all three elements. The process of requirements, design and construction, all these parts start with the NASA safety and mission assurance requirements. There also has to be a process where there is not excessive creep in these requirements which could result in cost increases and launch schedule delay.

Unfortunately, the Augustine report gave just a very brief mention of crew safety for launch, orbit and recovery operations. The report had no in-depth discussion of these vital issues of safe launch to orbit and return to Earth of government crews. If NASA can provide incentive seed money, can industry raise or finance the funds? What are the safety requirements for commercial government crew vehicle? That must be commensurate with other government operating crew transport systems.

The commercial entities that propose to provide safe government crew transport will require a guarantee of a certain number of flights for a certain period of time and a price in order to minimize or to recover the reoccurring investment and have a satisfactory return.

A major issue is, who assumes liability for the safe government crew delivery. If it is commercial, would insurance be available and at what cost? If safe commercial flight transportation for government crew does evolve, other questions will arise. On page 72 of the committee report it states, "It is critical to the success of the program that multiple providers be carried through to operational service," and that statement in itself has a huge financial implication for both the government and the commercial providers. If NASA is buying a government crew ride rather than a spacecraft, then how, by whom and to what standards will the government's equipment and operations be certified? What entity other than NASA can establish and verify appropriate standards for human spaceflight? That question becomes very crucial.

Madam Chairman, thank you and the members of the Subcommittee for the opportunity to express my opinions. I will be glad to respond to any questions you or the other distinguished members have. Thank you.

[The prepared statement of Lt. General Stafford follows:]

PREPARED STATEMENT OF LT. GENERAL THOMAS P. STAFFORD

Chairwoman Giffords, Ranking Member Olson, and Members of the Subcommittee, I am honored to be invited to appear before you today to testify on the matter of crew safety in human spaceflight. In the wake of the Augustine Committee report, it is imperative that the implications of that Committee's recommendations be considered carefully before this Congress directs, or allows, changes to be made to the program NASA has pursued and the Congress has approved for more than four years.

Before proceeding to answer your questions, I would like to make a few observations concerning the Augustine Committee report.

The most important observation of that Committee, and the underlying concern in all deliberations on the future of U.S. Human Spaceflight, is that it has been inadequately funded for many years now. The budget projected for NASA in the next decade and beyond is inadequate to accomplish the core objectives with which NASA has been charged. The funding is inadequate to build a timely replacement for the Space Shuttle, to return our astronauts and other international partner nations from the Space Station to the Earth and then to visit the moon, near-Earth asteroids, and to develop the technology and systems required for the first human voyages to Mars.

This plan for NASA has been approved by the Congress. It is a program offering the strategic vision for human spaceflight that was demanded by Adm. Gehman and the Columbia Accident Investigation Board. It is a program worthy of our nation. The Augustine Committee notes that at least three billion dollars per year must be added to NASA's appropriation to accomplish the mission. Even more importantly, the Committee notes that there is no other worthwhile program of human spaceflight which could be accomplished for the amount of money presently planned for NASA.

The choice is now plain: either we will provide the funding necessary to accomplish worthy objectives in space, or this nation will cede its leadership on the space frontier to others. I wish to add my voice to those who say that this leadership, the result of five decades of effort purchased at the cost of nearly a trillion of today's dollars and many lives, some of them given by close friends of mine, must not be allowed simply to drift away. As a nation, as a people, we must be better than that.

Today, I want to acknowledge the intense work performed by the Augustine Committee to cover these broad based subjects in such a relatively short period of time. After extensive examination of the Committee's report, I strongly agree with the majority of their findings and recommendations. I also strongly agree that the NASA Administrator, who has been assigned the responsibility for the management of NASA, needs to be given authority to manage NASA. This includes restructuring resources, the workforce, and facilities to meet mission needs. However, on some of the Committee's findings, I have a different opinion.

I agree with the Committee's recommendation that the remaining Space Shuttle flights should be launched on a schedule that is compatible with the normal procedures used for safe check out test and launch operations, which may extend the flights into 2011. We presently have a Shuttle at KSC on standby to launch on short notice, if required. If funding were available this Shuttle could carry cargo delivery that would enhance the viability of the ISS six-person crew capability.

The Committee wisely recommends the extension of the International Space Station past 2015 to at least the year 2020. However, the ISS will never be fully and effectively utilized unless researchers in all of the ISS partner nation have confidence that it will be supported and sustained as long as it is operationally viable and technically useful.

To have and to use this great international laboratory requires a guaranteed space transportation capability to be available as soon as possible after Space Shuttle retirement. The Committee recommends that this responsibility be removed from NASA and offered to commercial providers.

I would like to differentiate the two subjects, Potential Commercial Cargo delivery to the ISS and Potential Commercial Government Crew delivery to the ISS. NASA has incentivized and selected two contractors to provide commercial cargo delivery to the ISS. For commercial cargo delivery, the first issue is the development of a reliable booster to low earth orbit. The second issue is to develop an autonomous transfer vehicle to transport cargo from the booster to the ISS in a safe manner that would meet the stated ISS visiting spacecraft requirements that were complied with by the European Union Space Agency ATV and Japan's HTV. The development of this type of a transfer vehicle is a major challenge. The European Space Agency recently delivered their first ATV payload approximately four years later than their initial target delivery date. Japan delivered their HTV some two years later than their initial target date. Both government entities used considerable resources to develop their individual transfer vehicles. I certainly wish the two U.S. entities success in meeting their NASA milestones for cargo delivery since the ISS is dependent upon a continued supply of cargo deliveries by the partners.

With respect to commercial crew launch delivery to the ISS, I would like to recall my own experience. I have flown two Gemini missions on a modified TITAN II, ICBM, booster and two Apollo missions, one on the Saturn IB and one on the giant Saturn V. Over a period of thirteen years, I have experienced and participated in the development of high reliability boosters, spacecraft, and launch abort systems. I was a back-up pilot for the first manned Gemini spacecraft and spent many months in the factory and countless hours of testing in the spacecraft as it was being built and tested. I was then pilot of Gemini VI, the world's first rendezvous mission. On that mission, the TITAN II first stage engines ignited and then shutdown at T=0. Wally Schira and I had the lift off signals and a fire broke out below the base of the booster. The emergency detection system that had been installed on the TITAN II helped us to resolve the two critical failures that we experienced in that extremely short period of time.

I was the back-up commander for the second Block I Apollo flight and had my crew performing a similar test, in the sister spacecraft, at the same time that the Apollo I accident occurred and the crew died in the spacecraft fire on the launch pad. I was then back-up commander of the first Block II Apollo spacecraft, Apollo VII, and spent considerable time in the command module which was being built and tested. There were also numerous NASA engineers, inspectors and support technicians at the factory to facilitate this effort. This support effort was similar to the Gemini program, where numerous NASA engineers, inspectors and support technicians participated in the manufacturing and test at the factory. I was then the Commander of Apollo X, the first flight of the Lunar module to the moon. Again, I spent an inordinate amount of time in performing test and check-out in the command module and the lunar module.

My fourth mission, I was commander of Apollo for the Apollo-Soyuz Test Program. Again, I spent considerable time for the test and check out of the Apollo spacecraft and a brief time in the Soyuz spacecraft. These flights, both as a prime and as a backup crew member were accompanied with hundreds of hours of training in different types of spacecraft simulators and mockups where numerous emergency situations were simulated and resolved.

Therefore, safe delivery of a government crew to the ISS involves the human rating of the launch vehicle, the spacecraft, and the launch abort system, and the successful integration of all three elements. The process of requirements, design, and construction all begin with the NASA safety and mission assurance requirements. There also has to be a process where there is not an excessive creep in requirements that would result in cost increases and launch schedule delays of the vehicles. The Augustine Committee report gave just brief mention of crew safety for launch, orbital, and recovery operations. Unfortunately, there were no in-depth discussions of the vital issue of safe launch to orbit and return to earth of government crews.

It may be that the complexity of developing a new government crew space transportation capability, and the difficulty of conducting spaceflight operations safely and reliably, it is not fully appreciated by those who are recommending the cancellation of the present system being developed by NASA, and the early adaptation of the presently non-existent commercial government crew delivery alternatives. There seems to be some belief that if NASA would "step aside", private alternatives would rapidly emerge to offer inexpensive, safe, reliable, dependable government crew delivery space transportation at an earlier date.

Human spaceflight is the most technically challenging enterprise of our time. No other activity is so rigorously demanding across such a wide range of disciplines, while at the same time holding out such harsh consequences for minor performance shortfalls. Aerodynamics, aerospace medicine, combustion, cryogenics, guidance, and navigation, human factors, manufacturing technology, materials science, structural design and analysis—these disciplines and many more are pushed to their current limits to make it possible and just barely possible at that, to fly in space. Space is very, very hard.

We've learned a lot about human spaceflight in the last five decades, but not yet nearly enough to make it "routine" in any meaningful sense of the word. As Adm. Gehman and the CAIB outlined, these flights in the past have been developmental flights and the relatively small number in the future will be the same. Thus far, it has been a government enterprise with only three nations yet to have accomplished it. Development of new systems is very costly, operational risks are extremely high, and profitable activities are elusive. It may not always be this way, but it is that way at present.

Apart from questions of technical and operational complexity and risk, there are business issues to be considered if the U.S. is to rely upon commercial providers for government crew access to space. It is not that industry is incapable of building space systems. Far from it. It is American industry which actually constructs our nation's space systems today, and carries out most of the day-to-day tasks to implement flight operations, subject to the government supervision and control which is required in managing the expenditure of public funds.

So the question is not whether industry can eventually develop government crew delivery systems and procedures to fly in low Earth orbit. It can. The relevant questions in connection with doing so commercially are much broader than that of the relatively simple matter of whether it is possible. Let us consider a few of those questions.

Absent significant government backing, will industry provide the sustained investment necessary to carry out the multi-year development of new commercial government crew delivery systems to LEO? Will industry undertake to develop such products with only one presently known customer, the U.S. Government? What happens if, midway through the effort, stockholders or boards of directors conclude that such activities are ultimately not in the best interests of the corporation?

What happens if, during development or flight operations, an accident occurs with collateral damages exceeding the net worth of the company which is the responsible party? A key lesson from the development of human spaceflight is that safety is expensive, and the failure to attain it is even more expensive. Apollo 1, Challenger, and Columbia have shown that spaceflight accidents generate billions of dollars in direct and collateral liabilities. Who will bear this risk in "commercial" space operations? If the company, how much insurance will be required, where will it be obtained, and at what cost? If government indemnification is expected, upon what legal basis will it be granted, and if the government is bearing the risk, in what sense will the operation then be "commercial"?

When commercial government crew delivery space transportation does come about, other questions will arise. Will there be competition in this new sector, or will there be a monopoly supplier? If NASA is to contract with the first, or only, commercial government crew space transportation supplier, and if there is no price ceiling established by a government alternative, how do we ensure a fair price for the taxpayer in a market environment in which the government is the only customer for the products of a single provider? And how is a space operation "commercial" if the government is both regulatory agency and sole customer?

Leaving aside technical, operation, and business concerns, there is the matter of the schedule by which these new commercial systems are expected to come into being. The Augustine Committee has been particularly pointed in its clams that, with suitable government backing, such systems can be made before the comparable Constellation systems, Ares 1 and Orion, could be ready. Page 71 of their report offers such a claim.

Are such claims optimistic? Any launch system and crew vehicle that can transport a half-dozen people to and from the ISS, and loiter on-orbit for a six-month crew rotation period while serving as an emergency crew return vehicle, is necessarily on the same order of complexity as that of the old Saturn 1 and the Apollo systems. The Saturn 1 conducted its first test flight, with a dummy upper stage, in October 1961, and carried a crew for the first time in October 1968. The Apollo VII spacecraft which carried that crew, of which I served as back-up Commander, began its own development in 1962. Thus, the Earth-orbital segment of the Apollo system architecture required a half-dozen years and more to complete. These developments were carried out by highly experienced teams with virtually unlimited development funds in the cause of a great national priority.

If, in the fashion of airline travel, NASA is buying a ride rather than a spacecraft, then how, by whom, and to what standards will the company's equipment and operation be certified? How is NASA to determine that the system is truly ready to fly? Does the government merely accept the claims of a self-interested provider, on the basis of possibly very limited flight experience by company pilots? We certainly do not do that for military aircraft, and even less so is this the case for civilian transport aircraft. Extensive development and hundreds or even thousands of hours of flight testing followed by operational test and evaluation by the government is required before a new military aircraft is released into operational service; I've done that kind of testing. Similarly, new civilian aircraft are subject to extensive testing involving certification of systems and hundreds of flights to exact certification standards before they are allowed to be put in passenger service. Will we accept less for new, "commercial" space systems which carry government astronauts, or those of our international partners? In my opinion, the Congress should certainly not accept less.

Yet, today, we do not even know what standards should exist for the certification of commercial spacecraft to carry government crew members into orbit. What entity other than NASA can establish and verify appropriate standards for human spaceflight? I will tell you that from my perspective and from the history that I have lived, these standards, like airworthiness standards, are written in other people's blood. Some of that blood was shed by friends of mine. We don't know enough, yet, about human spaceflight to relax the hard-learned standards by which we do it. And we certainly do not yet know enough to make the assumption that new and untried teams can accomplish it on a schedule that is better than was achieved during Apollo.

This takes me to another point. Some of you may recall that, a few years back, I chaired a Task Force on International Space Station Operational Readiness. This task force was charged with making an independent assessment of our readiness to put crew on the ISS, and to sustain it with the transportation systems, Russian and American, which were necessary for cargo delivery and crew rotation. We did not take this matter lightly. The ISS was new, and much smaller. We did not then have the years of experience we have since accumulated in building the ISS and flying on it. Our then-recent long-duration spaceflight experience had mostly been accumulated during the Shuttle-Mir program, and Russian experience in resupplying the Mir and the earlier Salyut space stations was not unblemished. Numerous docking failures had occurred over the lifetimes of these programs, resulting not only in cargo which went undelivered but also, in one case, the collision of an unmanned Progress resupply vehicle with the Mir. An in another instance there had been a fire on Mir itself and the first crew to visit their first very small space station Salyut died after performing the orbit maneuver to reenter the atmosphere.

These indicants and accidents gave us pause. Not because we doubted the capability of the team; the Shuttle had been flying for over fifteen years by that time, and the Russians had accumulated decades of experience in long-duration spaceflight. I've flown with them; I know how capable they are. No, our concerns were heightened by our awareness of just how careful one has to be in this most demanding of enterprises. We cannot afford to relax that vigilance today as we go forward into a new era of ISS utilization, and as we prepare once again to voyage outward from Earth, first to the moon or the asteroids and then beyond. There is a place in these plans for the contributions of commercial government crew space transport entrepreneurs, but not yet demonstrated, and not to the exclusion of NASA's own systems.

I have asked many questions in this testimony, questions which I believe must be answered if commercial government crew human spaceflight is to become viable. I believe that these questions and others yet to come can and will be answered at some date. However, America's continued leadership in space should not depend upon the nature and timing of those answers. When commercial entities can provide dependable transportation reliable, U.S. government crews as well as partner nation crews, the government should buy it. But until that time, there should be an assured government capability to accomplish the task.

Thank you.

Chairwoman GIFFORDS. Thank you, General.

I want to thank all of our witnesses today, and we are really blessed to have such a star-studded group of individuals with lifetimes worth of knowledge and expertise.

We are going to begin our round of questions now. I am going to start with 5 minutes, and because we have so many members, I will try to really make sure that we all speak for five minutes including cutting myself off.

SAFETY OF LAUNCH SYSTEMS

Let me begin with something that Dr. Fragola had put in his testimony and touched on it with his slides. You had stated that it was your belief that the Ares I launch vehicle because of its inherent focus on being as safe as achievable from the very beginning has the best chance to be outstandingly safer in terms of it being a crew launcher. You talked about that as a good way to begin from just the very start. Given the fact that we are under enormous budget constraints here in the Congress and that funds available for NASA's human spaceflight and exploration program are always going to be more constrained than we would like, we need to think about how we prioritize, and I would like to hear from I think General Stafford and Mr. Marshall on how important a factor should the inherent safety of the Ares I vehicle be for Congress to consider as we make a decision on which launch system or systems to pursue in meeting NASA's International Space Station and exploration needs. I would also like to hear whether or not this should be the inherent safety of the Ares I, should this be a significant discriminator when choosing among alternatives and also who should carry the burden of proof? General, let me start with you.

Lt. Gen. STAFFORD. Madam Chairwoman, again it starts with the requirements stated there by the NASA Safety and Mission Assurance, and I noticed that the astronaut group had stated their own requirements, that the reliability of the crew from launch into orbit is three nines. In other words, you have had a failure no more than one out of 10,000. I did my own review and my best memory back from Apollo, and we were striving for four nines at that time, Madam Chairman, 40 years ago, and just to be sure that I had this right I checked with Dr. Chris Kraft, who was there with the space task group and director of mission operations and then was later center director, and he said that they were striving for four nines, and in fact, Dr. Kraft said he would like to give a few of his thoughts on his how to distinguish reliability of boosters.

"Since the first time a pencil was put to paper, the engineers and technicians are all responsible that the vehicle be used to carry astronauts and others into space. They know that the life of the individual depends on it. This is true of the first-level engineer, the lead designer, the chief engineer, the program manager and company executives. This is also true of the machinists, the contract buyer, the piece part selector and the safety, reliability and quality control experts and the test engineers and eventually by the person who has to stand up on launch day and say 'go' when that launch director asks.

"In my opinion, that is the case for the Ares I and Orion. It is not the case for the COTS-crewed government vehicles. To think that it is the large and dedicated oversight, you know, group could provide the same amount of credibility and reliability and safety and quality for a machine is to say that the first paragraph was misunderstood and has probably not been experienced."

So it starts right from the very start. And I know from my own experience that the Titan II had several dead zones in it. That program in Titan Gemini was a high-risk demonstration program only.

Chairwoman GIFFORDS. Thank you, General.

Mr. Marshall?

Mr. MARSHALL. Well, first of all, as you have heard today from this panel, I think everybody agrees that safety has got to be an integral process of selection and enforcement of any vehicle that is used in the future for human flight to provide astronaut travel to any place in low earth orbit or beyond. So I think that that is an absolute given that it has to be fundamentally thought through from the very beginning. That said, the ASAP has had the opportunity to look and observe the evolution of the Ares process. We have challenged Jeff and his team on numerous occasions and we have been very, very impressed by the product and the processes that they have employed. The commercial side is just now beginning, and as I noted in my opening statement, we, the ASAP, believe actually that NASA is behind because they haven't articulated what the requirements are from a human ratings requirement. We find good receptivity from the commercial providers thus far but the truth is, if they are building vehicles today and we would rather have had those rating requirements articulated so that they could be integrated into the design processes at that moment rather than let them transpire and move forward for integration at some other time. So we are very concerned about where the COTS–D program or the like or similar name is in this process case, so the basic bottom line is, safety has to be a primary consideration in any selection of any vehicle.

Chairwoman GIFFORDS. Thank you, Mr. Marshall.

Next we will hear from Mr. Olson.

NASA—COMMERCIAL INDUSTRY: SHARING OF SAFETY STANDARDS

Mr. OLSON. Thank you very much, Madam Chairwoman, and I would like to follow up on Mr. Marshall's comments but with you, Mr. O'Connor. I mean, that is one of the criticisms we have heard about the COTS–D program, NASA's commercial space, is that NASA is behind in getting the information to the industry as to what they need to do to become human rated. And so could you briefly explain how NASA uses its human rating requirements to tailor the design of a particular crewed system such as the Ares and the Orion, and again, following up on the line of questioning of Mr. Marshall's comments, if the human rating requirements are the top-level requirements, how would a potential commercial provider gain the insight to design a system that meets NASA's requirements? And one more question, how did NASA get comfortable enough to finally certify the Soyuz for human spaceflight?

Mr. O'CONNOR. Yes, sir, glad to answer those. The first part of this is the commercial crew transport. Currently, there is no formal start of that program. We have been talking about it. We have asked for people to—commercial companies to give us information on how they think that might go. We have made our regulations, our policies, our requirements known. All that have asked for them, we have made them available. As I mentioned, even those things that are not yet transformed into requirements and standards, the results of the survivability study that we did in 2008, that has not yet been flowed into a set of standards but we tried to make that available as well. The human rating requirements document at the top level is 31 technical requirements, or what I call "shall" statements. It is very limited. It is very top level. It is the kind of thing that says that shall have an abort escape system, you shall have failure tolerance in your design. But in the beginning of that document it says that there are three pieces to this. The first piece is that you are expected with your design to do all the things in a NASA development that are required throughout the whole set of standards and requirements, not just those 31 but all the mandatory standards and requirements are given before you get into this human rating requirements document.

This is where tailoring comes in. We spent six to eight months with the Constellation team and my team going over the flow-down of all the safety and mission assurance requirements. These requirements come in the form of documents that are called mandatory standards or mandatory requirements. But in order to know which of the "shall" statements that are embedded in those things really apply, you have to go through a pretty thorough flow-down activity and we did that with Constellation. It took about 6 to 8 months to go through that tailoring process to figure out for this particular concept, for this particular mission, for this particular design which of our "shall" statements would apply. We also invited the team to come in with alternatives. There is a NASA standard but there is also alternatives. Industry has some standards, for example, on how to do soldering and so on. We start with the NASA standard but we invite our contractors and our projects to come in with alternatives if they think they can do it just as well. This is part of that "Yes If" thing I was telling you about earlier.

Now, as far as something that we don't design because our NASA human rating requirements document is for a NASA development. Now, in the past we said we would like to fly with the Russians. We would like to fly one of our astronauts. Norm Thagard back in 1995 flew on the Soyuz. The Soyuz was not built to any given NASA standards of the day. It was built to Russian standards back in the 1960s. The process for building and assembling and launching the Soyuz was not to NASA standards. It was to longstanding Russian procedures. To get to the comfort level we needed to fly our person on their mission, we spent about three years with some of our best engineers working with the Russians to understand the equivalence of their system. We know they don't do things exactly the way we do but can we get confident about it, and we took some time and a lot of good people to develop that confidence, and in the end we got to the point where we believed that even though they may not do things exactly the way we do, we are confident to the same level that we would if we were flying them on one of our systems. This business of acceptability of risk is part meeting requirements. It is also part building the confidence where the requirements don't exist or where they are someone else's requirements. We need to do a risk-informed confidence-type activity to get to where we feel comfortable doing it.

Mr. OLSON. Well, thank you for that very thorough answer to my question. I see my time is over. I yield back.

Mr. MARSHALL. Sir, may I make an addition if I may?

Chairwoman GIFFORDS. Yes, Mr. Marshall, just briefly, though.

Mr. MARSHALL. I just wanted to report that we have followed up with NASA as to where they are. We received a detailed briefing in November and are satisfied that the approach that they are moving forward is now appropriate and timely.

Mr. OLSON. Thank you, Mr. Marshall.

Chairwoman GIFFORDS. Thank you, Mr. Olson.

Dr. Griffith, please.

POTENTIAL IMPACT OF CONSTELLATION PROGRAM ON COMMERCIAL SECTOR

Mr. GRIFFITH. Thank you, Madam Chair, and thank the panel for being here. We have been in numerous, numerous hearings prior to the Augustine report and after the Augustine report. Each time the Ares I comes to the top as a respected and well-thought-out plan some four, five years in the making. The successful test of Ares I–X was an achievement that we truly, truly appreciated and with the 700 sensors that were mentioned and the data that is going to be collected, it seems to me that the commercial aspect of this was an introduction into the Augustine report that was fascinating and it is greatly discussed but it is not hard science as we have now today with documentable evidence of safety. It is probably three, maybe four or five years out and it seems that we could achieve our commercial aspirations in space by developing the Ares I to the point where it is reliable, consistent. Our solid fuel engine is reliable. Our liquid fuel motor is reliable. Our Orion capsule is going to be reliable. We have every reason to believe that it is and it seems like our steppingstone into the commercial venture is successful development of Ares where it can be insured, where we can be confident that our human spaceflight, our astronauts can be insured and it can be successful.

My question is, why wouldn't we take the approach of asking our government to fund the Constellation project with the idea in 36 months or 48 months we could transfer much of that information into the commercial sector with a great deal of confidence and not delay the challenge that we are facing with China, India and Japan? Mr. Alexander, would you address that, please?

Mr. ALEXANDER. First of all, I think it is important to remember that Ares, Orion, particular Orion, is designed for exploration beyond LEO. It is a spacecraft whose prime purpose is to take—originally designed to take people to the Moon and back and the space station if necessary if there were not alternatives. As such, it is a more complex spacecraft and more expensive spacecraft than I think what you would want to do commercially. As for the Ares I rocket in terms of commercial use, I think you also have an infrastructure, a per-flight cost that would be prohibitive from a commercial perspective. That being said, the Commercial Spaceflight Federation, you know, takes no position over whether the Ares I program should continue as is or should be changed or Orion for that matter. I personally believe that, you know, this country needs an exploration program and it needs a crew exploration vehicle like Orion to go beyond low earth orbit. That is very important for the Nation's human spaceflight program. But at the same time, we don't need to be serving all missions with the same vehicle because then you are not optimized for any one mission, and I believe and I think the Augustine Committee found that the capability or the technology, the knowledge is resident in U.S. industry to do crew transfer and cargo transfer to low earth orbit and that if NASA wants to get on with the business of exploring beyond low earth orbit, it needs to transition operational tasks like that to commercial sector so that it is not continually taking on more obligations than it can afford to take on.

Mr. GRIFFITH. Thank you.

HUMAN RATING FOR COMMERCIAL SECTOR

Mr. Hanley, the timeframe for human rating on Atlas or Delta for the astronauts would be what? What would we look at if we said today that we are going to develop commercial sector with taxpayer-funded money and a commercially or human-rated launch vehicle?

Mr. HANLEY. Well, the work that we have done over this last year, we had a study that was performed by the Aerospace Corporation for NASA. They projected, and I am going on memory now—we can get an answer for the record if I misstate this but I believe it is on the order of six years from start to develop a system that would have been derived off the Delta IV heavy launch vehicle. That booster as Aerospace studied it would have used the existing core stage and a new upper stage. Not included in that study, of course, were the implications to the Orion if Orion had to change at all, and that would be something that would have to be further studied.

Mr. GRIFFITH. Thank you.

Thank you, Madam Chairman.

Mr. ALEXANDER. Could I follow up on that, please?

Chairwoman GIFFORDS. Sure, Mr. Alexander.

Mr. ALEXANDER. That study as described by Mr. Hanley was talking about a Delta IV heavy vehicle that is for the Orion spacecraft to low earth orbit, a 25-metric-ton spacecraft. It did not address or at least in the comments did not address the Atlas V version vehicle which has flown 19 times successfully, which would be used to put commercial crew capsules that are on the order of 8 to 12 metric tons up into low earth orbit. So it is not an apples-to-apples comparison to talk about a six- or seven-year human rating process for one vehicle when in the commercial world we are talking about a different vehicle that has already, you know, achieved a certain demonstrated reliability, would go through a human rating process but is certainly not at the six- to seven-year timeframe.

Mr. GRIFFITH. But what would be your estimate other than the six to seven years. Would you say three?

Mr. ALEXANDER. I would say that. I think the capsule is what is going to drive the timeline, not the human rating and the launch vehicle.

Mr. GRIFFITH. Lieutenant General?

Lt. Gen. STAFFORD. The experience we had with the Gemini Titan, and that was an all-out push, was 39 months. It was over three years. And we had some dead zones in that, and I don't see how this could be any sooner. It will probably be longer. One thing I might add about this gap, and I would rather not transfer money to Russia just like anybody on this Committee would, but I think one thing to look at that has occurred is that the OMB to me in de facto has set space policy when they came in and cut money back and said you will finish—first originally came in just a person over there a second-level tier said the Administrator will finish it, 15 flights 2008, they said, but the President said we are going to complete the space station, phase out the shuttle and said maybe so but this is what it is. So to me, there needs to be an institution, someone like the National Space Council used to have that would oversee that so that second-level tier and groups like that would not cut back. If the proper money, it is my understanding, sir, had been applied, we would have had the Ares Orion flying in 2012 or 2013 so there would not have been too much of a gap. And I don't know that the President ever really got the word back because he had other major issues on his desk at that time like Iraq and Afghanistan.

Mr. GRIFFITH. Thank you, Madam Chair.

Chairwoman GIFFORDS. Thank you, General Stafford. Thank you, Dr. Griffith.

Next we will hear from Mr. Hall, please.

PROGRAM MANAGEMENT AND SCHEDULING ISSUES BETWEEN CONGRESS, ADMINISTRATION, AND NASA OVER TIME

Mr. HALL. Thank you, Madam Chairman.

General Stafford, you worked in the space program for many, many, many years and you spanned a lot of days from Apollo to the current shuttle program, and I think you are about as knowledgeable as anyone I know, and you know we are looking for a way to save the program that I guess the last four or five or six Congresses have agreed on to pursue, and that involves having to address that four-year gap in there, and if I may be wrong, I probably am, but it seems like to me that we need about $2 billion a year additional for about four years to make that happen. And what that would do would preserve our leadership in space, would preserve our space station, would preserve our friendship with some partners that have been good partners in space. What was your experience during the Apollo program in working with Congress and the Administration on program management and scheduling issues, and could you highlight the major distinctions between then and now? It was a lot easier then than it is now, and I think we just have to keep insisting that the President either in the next address to the Nation comes on in and recommends what we have all asked for and what I think everybody on this Committee here wants, to save our space station, save our position in space and not have to rely on Russia for anything. You might just in a minute or so if you can just kind of compare those times with today.

Lt. Gen. STAFFORD. Thank you, Mr. Hall. The President's policy was carried out completely with the help and approval of the Congress. The National Space Council that was chaired by the Vice President helped oversee that and the OMB followed in line, and as I mentioned just previously, it appears that in certain cases the OMB in de facto is setting space policy, and this is one of the real issues. Also, we have today Continuing Resolutions that we didn't have in those days. But if the President sets a policy, it should be carried out and the funding you said would certainly do it, so we could have had the Ares Orion flying in 2012 or 2013 so there wouldn't have been much of a gap in this. Thank you, sir.

Mr. HALL. Any others want to make any comment on that? You are all experienced and you have been around all a while. You know, not too many years ago we almost lost the space program by one vote in Congress, and that alerted everybody from schoolchildren and everybody else that is interested in the space program. It even caused a fine old man like Dr. DeBakey to come and walk out all four of the floors here in the Rayburn Building to talk to everybody, and a lot of them couldn't find time to talk to him because they didn't want to tell him no. But that following year I think we passed the program by something over 100 votes, 120 or something, but then we all got together on it. I am just wondering what kind of pressure we can put on the President of the United States to come out with a recommendation. Of course, back in those days, that is before Katrina and before the vicissitudes of nature had set us back in several of our states and 9/11 and 8, nine years of war. We are in a little different situation. But you know, if you can throw away $350 billion on AIG and not even know where it is going or not ever receive an accounting for it, they can find $2 billion a year for the next four years for us to save a program like the space program. It is a lot harder to do now but you six men are leaders and more knowledgeable than anyone I know—this is the best panel I have seen up here in a long, long time—to put your shoulder to the wheel and every chance you get talk to the President, talk to the czar, talk to whoever you have to talk to to get into it. But we need to save this program. We need to go forward with this program and we don't need to fall back behind or have to battle with China or any other nation. We just have to assert ourselves some way and find that money. If we are going to have all these bailouts, this is an awfully good place for one right now. Save the program. I have even thought about trying to alert all the schoolchildren of America for write-ins to get them to write in what they think about it because they are the real loser or beneficiary of what you do and what this Congress is going to do this year and next year with regard to the space program.

But you see a lot of difference in then and now, don't you, Tom?

Lt. Gen. STAFFORD. Mr. Hall, I certainly do. It is a different era. In the cooperation between the President, the Congress, the OMB, it is completely different, sir. I wish it could be like that. In fact, it could be possibly a recommendation from me to this Committee to say that the OMB should follow the policy of the President.

Mr. HALL. And then we want to talk to the President. I yield back. I think I have used my time. Thank you, Madam Chairman.

Chairwoman GIFFORDS. Thank you, Mr. Hall.

One of the reasons why we have held so many hearings, two hearings ago we had a fascinating panel of experts to talk about tech transfer from NASA because in so many ways the accomplishments of NASA go beyond just exploration or go beyond what we can physically see up in space right now, but from the airline industry to the medical industry, computers, it has been extraordinary the gifts that NASA has given to our country and to the world and so part of our job on the Subcommittee is to make sure that the American people, the President, other Members of Congress understand that as well.

Next we are going to hear from Ms. Edwards.

IMPLEMENTATION AND APPLICATION OF SAFETY STANDARDS

Ms. EDWARDS. Thank you, Madam Chairwoman, and thank you to the panel. Every time we have these hearings, I learn something new. In my mid-20s I recall sitting in front of a monitor at Goddard Space Flight Center, the elation of a launch in January 1986, the confusion thinking that there was something that we had done wrong in our communications on that day, and then the absolute silence of silence, unlike any I have ever heard over our colleagues as we realized the disaster that had happened with the *Challenger*. And I think at that time I think all of us, no matter what we did believe, that we paid great attention to safety and obviously the investigations that followed demonstrated that there were huge gaps in safety, pockets where there was a lot of attention to safety and other pockets where there wasn't, and we even to this day and after the *Columbia* disaster continue to point to some of those same gaps, and I think, you know, safety has to be north, south, east and west in NASA whether the services and work is being performed by a contractor or internally at NASA and so I appreciate the testimony today.

In looking at the Augustine report, there is really actually very scant mention of safety in the report I think as General Stafford pointed out and so one of the questions that I have really is, and especially with the principles that I think Dr. Fragola, you outline, how you would take those principles today and actually even apply them to *Challenger* and to *Columbia* to see whether, you know, these design systems, for example, that had been, you know, launched—I don't know—25 times, I think when the *Challenger* disaster happened and we would have described those as, you know, pretty reliable, but whether those principles applied today would allow *Challenger* and *Columbia* to meet the mark as you have indicated that perhaps in the design and the concept of Ares you think that that would meet the mark.

Mr. FRAGOLA. The principal problem with the space shuttle is a lack of abort system, the lack of being able to address the recovery of the crew given an incident. The shuttle as a launch vehicle is among the best, if not the best in the world as a reliable vehicle but the shuttle points out very dramatically the difference between reliability and safety. I would also like to point out, having been involved in the original shuttle competition, the reason—one of the reasons we sought the shuttle was, we were concerned at the time about recovery of the Apollo capsule. We had had one failure where we lost one parachute and we were concerned about that system and we were therefore interested in designing a system that would address the failings of the past, and so we felt that a landed system, a system with wings, would improve on the recovery, and it certainly has improved on the recovery but it has increased the vulnerability in ascent and increased the vulnerability in other areas. So one of the things that I think we should learn from this is that we can't anticipate all the unknown unknowns in a system, and that is one of the reasons why it is essential to have a robust and well-tested system that is able to survive and abort safely. We didn't do that on the shuttle.

Ms. EDWARDS. So Mr. Marshall, I wonder if you would describe for me how it is that we could apply a set of safety standards and principles both within NASA and also in a commercial environment given our experiences?

Mr. MARSHALL. Well, you heard earlier that the FAA ought to be the licensing authority for commercial venue. We certainly agree with that and we think that there is a need to really aggressively develop that process. I am not an expert on that and haven't participated but my understanding is that the process is just beginning. Conversely, NASA establishes the crew safety requirements, and this is what I was talking to from a commercial venue. We, the ASAP, believe that NASA does a great job for its own government-controlled programs but that this process really needs to be accelerated from a commercial perspective if there is going to be movement and direction in that particular arena. So we think that it is a combination of both the licensing authority and the user of that, which is the NASA authorities, to aggressively develop the human rating standards that are necessary to provide for the crew safety.

Ms. EDWARDS. Thank you.

Madam Chairwoman, I know my time is expired. I obviously have tons more questions.

Chairwoman GIFFORDS. Thank you, Ms. Edwards.

Next we will hear from Mr. Rohrabacher.

Mr. ROHRABACHER. Thank you very much, Madam Chairman, and again, thank you for your leadership in this Subcommittee.

CONSTELLATION PROGRAM: HUMAN AND CERTIFICATION OPTIONS CONCERNS

First of all, let me just state, I am not opposed to the Constellation concept. I think that from what I have seen, the Orion and Ares system has a role to play. I am a bit worried that what we have here, however, is a mindset that I have seen before and a mindset that has failed before, and that is, trying to have one system that will serve all needs and thus actually bring down the chance of success of that mission or the ability of that mission to actually do a very great job in a specific area. I remember the Edsel car was supposed to be something for everybody and it turned out to be nobody in particular really wanted it because it was designed for everybody. I remember the F–111, which was an aircraft that was designed supposedly—I remember that during the early 1960s and it was supposed to be something that could fulfill every mission but then once they built it, none of the military people really wanted it because it really didn't fulfill any of the missions as well as they had hoped or what they wanted. I would hope that with Ares Orion, we are not making that same mistake trying to say that we have to have the same rocket and transportation system for low earth orbit that we have to have for other missions, later on the Moon, and I support the moon mission. That is why I think maybe the Ares Orion system is important in the long run but why in the short run do we have to have it fulfilling the same needs that we could perhaps serve—might be better served by making the Delta system, which is a very good system, been very reliable, or the Atlas V system, and just making them with the ability to carry people then and they can, I guess, man certified I guess is the words we are looking for. So why is it that we have to have—Mr. O'Connor, why is it that we have to have Ares doing everything rather than going with trying to do manned certification for Delta and Atlas?

Mr. O'CONNOR. Well, sir, this is a decision that was made some time back when we were looking at the vision and what we wanted to do with human spaceflight, and in the context of the mission, which was to have something that would take our astronauts to the moon as a steppingstone to further out, the concept included two different launch vehicles, one heavy and one light, and the light one was carrying crew. And by definition, the light system that carried the crew had to be able to take the crew to low earth orbit. Now, the Orion was designed——

Mr. ROHRABACHER. Having to do that doesn't necessarily mean it is the most cost-effective and the most efficient way of doing it.

Mr. O'CONNOR. Right, and I agree. It had to do that as part of the lunar mission, and if you simply said let us not worry about the lunar mission, let us do something just to low earth orbit, then you would start from scratch and say let us do something that is just for low earth orbit, and you may not have the Ares Orion system.

Mr. ROHRABACHER. We spent a lot of money on the Delta and Atlas systems over the years and they have proven themselves in terms of actually launch systems. I don't know, we haven't put people on them but they have proven very reliable in that. Again, I don't—and by the way, I support the moon mission. I think the moon mission is a good mission and that is why I support the Ares Orion system but suggesting that we then have to because that is going to be used for a later mission, we have to use that rather than Delta or Atlas, I don't think it makes sense. There is something that doesn't—I am going to have to study this a little more. It just doesn't seem to come together for me that that is a requirement.

Mr. O'CONNOR. Yes, sir. You know, when we looked at this—and I am going to defer to the program manager on this because he has looked at it harder than I have but just from my view as the safety guy, it seemed to me that either one of those two options was an F–111 equivalent. The Atlas and Delta are not designed to carry people in space. They don't have the structure for it. They were designed for cargo, and they are very reliable but they would have to be significantly modified in order to do——

Mr. ROHRABACHER. Well, you know, reliability of cargo, what we are talking about is human cargo, and I don't see that as being in a totally different category. You just want to make things a little bit adjusted for human beings.

Well, my time is up. Thank you very much, Madam Chairman, and maybe we can have a second round if we have time.

Chairwoman GIFFORDS. Indeed.

Mr. Hanley, would you like to comment?

Mr. HANLEY. Just to address your concern with respect to the exploration mission and Ares I, the underpinnings of the Constellation's exploration architecture to go to the moon was integral to the decision to choose Ares I or something quite like it when those decisions were made. We began from the process of the design of the Constellation system with the moon in mind. The key driving requirements of Constellation, the preponderance are for the lunar mission. So we selected it because where we want to be taking our risk is on the lunar surface, not in the first 100 miles. And we leveraged off of the decision that we made on heavy lift, and because Ares I is derived from the infrastructure we need for the big rocket, the Ares V, you get it at sort of a marginal additional cost. The design of the first stage solid and the design of the upper stage engine on Ares I are the same assets that are used for the Ares V, so the production capacity is common for those.

Chairwoman GIFFORDS. Thank you, Mr. Hanley, Mr. Rohrabacher.

Ms. Kosmas, please.

Ms. KOSMAS. Thank you, Madam Chairman. Thank you, gentlemen, for being here today. This is obviously an issue of great importance to us here on the panel and also I think to the American public as we move forward and make every effort to maintain our leadership in space exploration for all the reasons that are obvious to us and that we attempt on a regular basis to make obvious to others, so we thank you for being here.

ESAS Recommendations for Human Space Flight

No question about the fact that safety is a very important concern. I want to chat with you a little bit about an article that was in today's Orlando Sentinel. I am from central Florida where the Kennedy Space Center is and so it is a big issue for us in our district with regard to what the next phase of space exploration will be, and also a great concern of course for the gap, but nevertheless, safety of course is very important. The story in today's Orlando Sentinel discusses the 2005 architecture study, ESAS, recommendation that after two test flights, the first five flights of the new rocket and capsule deliver only cargo to the International Space Station to establish a record of reliability before putting humans on board. The ESAS states it takes five flights in addition to the two test flights to surpass the shuttle safety level of one in 100. If there were no cargo flights beforehand, the risk of the first crewed flight after the two test flights would be approximately one in 40, or approximately two and a half times the shuttle. Adding cargo flights to ensure safety would only seem to increase the gap in U.S. human spaceflight capability.

So the question I wanted to ask was beginning with Mr. Hanley, I understand that the current plans propose putting astronauts aboard Ares I and Orion after only a single unmanned flight of the final rocket. Can you discuss this decision in light of the ESAS original recommendation and what steps are you taking to address this concern?

Mr. HANLEY. Certainly. As part of the program's preparation for its program preliminary design review that will be next year, next calendar year, we are putting together our integrated test and verification plan. The flight in which the crew will launch will be informed by that plan and it requires an understanding of the test program, and Joe talked about this earlier, the test program that goes into verifying that these systems will in fact perform the way that the designers believe they will. There is a lot of variability in the methods one might apply to try to use a crystal ball to predict how reliable a particular system will be. Coming up with an absolute number is very sensitive to the method or the approach, the thought process that you use, and that is what we see. So predominantly we use these risk numbers to compare alternatives, not necessarily to inform some absolute number of what the risk level really is. So with respect to the assertions made in the ESAS study versus what we are doing today, I would invite Joe to maybe comment because he was integral to the ESAS study.

Mr. FRAGOLA. And since I wrote that section that you referred to, that is a great confusion. If they had only gone to the page before, they would have seen that that statement referred to an advanced engine on the Orion spacecraft using LOX/methane. What we were trying to do was to enhance the reliability, the mission reliability of the lunar missions with a given performance. We were looking at LOX/methane because LOX/methane was able to be carried through as a launch propellant for Mars. What we wanted to show from a safety standpoint was that there was a penalty in immaturity to the system if we chose that LOX/methane option. So what you were seeing there was that penalty. If we look at the Ares system, Orion system today with the propulsion system that is now on Orion, which is essentially the same that is on the space shuttle OMS systems and has performed absolutely perfectly on the OMS and was also on the lunar module descent engine and on the command module serving as propulsion system, the immaturity of the system drops to almost zero and now the immaturity of the system is based on primarily the second stage of the Ares system. And if you look at what it takes for that to get to the equivalent of the shuttle, it is between one or two test flights necessary to get the equivalent of the shuttle. It is certainly not going to get to one in 1,000 at that point but we are looking at trading off versus when does it get to the point that the shuttle, which is what we are flying crew on today. So the statement in the Sentinel is correct but it applied to an option in the ESAS study, not the one that we are flying today.

Ms. KOSMAS. Thank you. Unfortunately, I am afraid that ended up using all my time, but thank you for the answer and I will see to it that that information is passed along. Thanks.

Chairwoman GIFFORDS. Thank you, Ms. Kosmas.

For the remaining member for our first round is Mr. Hill. Mr. Hill.

Mr. HILL. Well, thank you, Madam Chairman. I got here rather late so I need to get caught up on some of the conversations you have been having for the last hour or so, so I will pass on asking questions.

Chairwoman GIFFORDS. Thank you, Mr. Hill. We are glad you are here.

AVAILABILITY AND ECONOMIC VIABILITY OF COMMERCIAL CREW TRANSPORT

We are going to begin a second round. We have not had votes yet so it is our good fortune today, and while we have all of you here we are going to take advantage of it, so I would like to begin. I am going to ask everyone on the panel starting with General Stafford if you could answer two questions. Taking everything that we have learned today about safety and the complexities of what it takes to build these vehicles, is the timetable for availability of commercial crew transport truly realistic? That is my first question. And the second is, given the required steps of everything that factors into building these vehicles, do our witnesses believe that would-be commercial crew transport service providers be able to garner sufficient revenues from non-NASA passenger transport services to remain viable over this time period as well? So those are the two questions that I have. I know that you gentlemen come from different aspects and different angles of this industry. You know, the backdrop of course is in light of the fact that we have a diminished budget. I mean, if we had sufficient budget to do everything, I am sure that all of us on this Committee would agree that this is where we want to invest our money, I mean, because the benefits that come from both the private and public space sector is outstanding and much underappreciated. But given the fact that we have finite resources, I think that these are two important questions. I would like to begin with you, General Stafford.

Lt. Gen. STAFFORD. Thank you, Madam Chairman. First, on the safety for the commercial crew delivery for government crews, the observations in the Augustine report said 2016. If they would go to meet the requirements starting with safety and mission assurance, I think that would be a very tough goal to make it. They could possibly make it. But on the other hand, when they said 2017 for the Ares Orion, I do not understand that. It should be far sooner than that.

As far as other customers that the commercial crew delivery corporation would deliver to, right now, other than the space station, I know of no other ones that would be there at this time.

Chairwoman GIFFORDS. Thank you, General.

Dr. Fragola?

Mr. FRAGOLA. Well, certainly the challenge is a potential challenge that could be met by the commercial crew. It is a question of what the uncertainty involved is, and from my perspective based upon history, it would be very uncertain that we could meet that kind of a date. Certainly the type of work that has gone on in Ares since the time of ESAS to today to ensure safety in that vehicle is equivalent to what you would have to do on any vehicle, whether it would be a Titan or a Delta or an independent commercial launcher.

I would like to go back to that one thing that I said before to answer Mr. Rohrabacher. There is a big difference between a crew payload and a payload that is not crew because after the accident, the payload that is not crew doesn't care a whit about what happened but the payload that is crew cares a lot, so what we have to do is to design the abort system integral to the failure mechanisms that are on that system and that requires a much greater knowledge of your launcher than they have today with commercial payloads or for Air Force payloads.

Chairwoman GIFFORDS. Thank you, Doctor.

Mr. Alexander.

Mr. ALEXANDER. Thank you. I believe that the timetable as laid out by the Augustine Committee is realistic. That is seven years from now. Certainly I don't believe that the human rating of the launch vehicle is the long pole in the tent. I believe it is the development of a capsule to take people to the station and back. There are companies that say they can do it in significantly faster time than that and there are others that say it will take at least that long, and I wouldn't, you know, pretend to be the expert that is going to predict exactly what it will take. However, I do know that it will take longer if we do not start now. As I said before, I don't believe that, you know, Ares Orion and commercial crew are competitive. I think that you need to do both, so it is not about which one gets there first necessarily but I do believe that because servicing the station is a simpler mission, less complex, and you can use demonstrated reliable launch vehicles that will need modifications but not extensive modifications because they have a track record of 19 successful launches or heritage of 19 launches, that that is a realistic timetable.

Second, as to whether there are viable revenues from non-commercial or non-government sources, there is already a market for private spaceflight participants that have been paying between $25 million and $35 million to fly on the Soyuz. Those people spent 6 months of their lives learning Russian, training on Russian systems separated from their revenue-generating jobs that they have. I believe that if the United States industry were able to offer that capability, you would have a far greater number of people willing to take that on and pay that kind of money. Also, you know, with the hope that with commercial, the price comes down, that market becomes bigger, but there is also a market for other U.S. industries and other activities, microgravity research, et cetera, in space that is not efficiently served by NASA and the NASA process and I think that commercial will be able to find additional revenues there. They certainly will not be the bulk of revenues in the beginning but there is a place for—or there is a demonstrated market there now that will only grow.

Chairwoman GIFFORDS. Thank you, Mr. Alexander.

Mr. Marshall.

Mr. MARSHALL. Regarding the two questions, is the timetable realistic, in the ASAP's 2008 annual report, we made a statement that said that there is no evidence to suggest that the use of a commercial space industry vehicle can significantly close the gap. We stand by that statement. We have no evidence that would say otherwise. I think the term that is of importance is "significant."

ORBITAL SCIENCES AND SPACEX

The second is, given the steps, is there sufficient revenue to provide survivability. I mentioned to you in my opening statement that we have gone to both SpaceX and to Orbital Sciences. We were at Orbital Science this week, and during the presentation we asked their senior management if they had done a market analysis to find other revenue sources that would address this specific issue. The answer was no, we have not done the market analysis because we see no viable commercial requirement at this time. Now, I am not trying to put words in their mouths. That is just the way I interpreted it. I would think that that is a fairly accurate statement.

Chairwoman GIFFORDS. Thank you, Mr. Marshall.

Mr. Hanley?

TIMETABLE: COMMERCIAL CREW TRANSPORT

Mr. HANLEY. With respect to timetable, I can really only speak to what I would see as the challenges, and Joe has touched on them. I think it is—and I would agree with Mr. Alexander, I think it is about the spacecraft, it is about the launch abort system as well as the rocket. Joe, I think, spoke quite eloquently about how it is an integrated system. It needs to be designed altogether as an integrated system to be able to maximize crew safety, and I think that is where the real challenges lie for other developers. That is certainly where our focus has been for these four years, and so what kind of—what that does to the timetable or not I really couldn't comment, not having detailed knowledge of the plans and the alternatives. So with respect to revenue, I hope to maybe live to see the day when I can buy a ride, but as far as revenue, I really don't have a comment.

Chairwoman GIFFORDS. Thank you, Mr. Hanley.

Mr. O'Connor.

Mr. O'CONNOR. I haven't done an independent assessment of these schedules but I can just tell you as a safety guy watching program and project managers and contractors predict schedules for years, as I watch that happen, I have seen that sometimes they miss and some of the things that cause them to miss schedules is the down time after failure. Another thing is the lack of integration up front. If you don't do good integration up front, then you pay for it later and it takes time. I remember after *Challenger* we tried to retrofit an escape system on the *Challenger* and we flat couldn't do it. So it wasn't even a matter of schedule. It was just too hard. So getting early, getting things done quickly in the front part of a program that you are going to need later on can help with schedule because it takes much longer to fix things than to do it right in the first place, so that is all I can add to that, and I really haven't looked at commercial revenue at all so I wouldn't comment on that.

Chairwoman GIFFORDS. Thank you.

Mr. Olson.

ARES PROGRAM: SAFETY AND FUTURE IMPACT

Mr. OLSON. Thank you, Madam Chairwoman, and this is a question for all of you or anybody who wants to comment, but I want to get back to some of the issues, some of the concerns we were talking about about the Ares program, and as you all know, a couple of weeks ago we had a very successful test of Ares I–X, a vehicle that had over 700 sensors on board to measure many of the factors that that spacecraft was feeling as it went through its ascent, and I just want to get some comments from all of you. How does that level of technology that we have now, how does that increase our ability to develop a vehicle safely and not have necessarily the flight test that we had to have in the past, and one sort of side question to that is, how does development of Ares I help speed up the development of Ares V, you know, basically the same system in many, many ways. Does that allow us to accelerate the development of the Ares V? Mr. Hanley, you first.

Mr. HANLEY. Well, the way I think of it is that by developing Ares I we are in fact developing parts of Ares V today so we aligned our strategy purposefully back four years ago. If you will recall, coming out of the Explorations System Architecture Study, the Crew Launch Vehicle, as it was called at that time, the Ares I was called, was a four-segment solid plus an upper stage that utilized the space shuttle main engine and we purposefully at the agency level made a decision to change to the five-segment and J2-based upper stage because we wanted to leverage the early investment of dollars we were making toward building the heavy lift launch vehicle. So that is the synergy between Ares I and Ares V that a lot of folks miss. So we are building part of the Ares V rocket today with the five-segment booster with the J2X engine. We even purposefully will be looking to play forward the investment we are making in the avionics that guide the rocket as well. The hurdles that we face with building a larger rocket really focus on the core stage, the massive core stage in that system, and those are investments we have yet ahead of us.

Mr. OLSON. Thank you for the answer, Mr. Hanley.

Any other panel member care to comment? Okay. Well, that was my last question, Madam Chairwoman. I yield back the balance of my time.

Chairwoman GIFFORDS. Thank you, Mr. Olson.

Dr. Griffith, please.

COTS VS. CONSTELLATION PROGRAM

Mr. GRIFFITH. Thank you, Madam Chair.

Some in NASA have suggested that by taking on the risk of procuring maybe a commercial service to deliver astronauts to the space station that we will lower our costs and provide greater launch capability, yet the COTS program was to be a proving ground for commercial sector to deliver cargo to the station but to my knowledge, that has yet to happen. I don't know that any of the commercial orbital transportation service providers or the funding of that has been able to deliver what we had hoped that it would. It seems that we should require our commercial providers to prove their ability to deliver on these contracts or on these ventures that taxpayer funds have funded. And so my question is, and anyone can answer this, the commercial orbital transportation services, what evidence do we have, what hard evidence do we have that we can rely on them to deliver manned spaceflight in a more timely way than we have with our Ares I or Constellation project? Is there any evidence?

Lt. Gen. STAFFORD. Mr. Griffith, as I said, I did extensive examination of the Augustine report and I knew many of the members and have talked to them, I told them I would be giving testimony here today. In fact, this morning I talked to Dr. Crowley twice on my cell phone on his idea of multiple providers and his assumed cost on those commercial government crew delivery vehicles, and then I checked with Mr. Hanley here and so it was a wide variance between their assumptions and what we have, and also I found that there was also, on the Augustine Committee there was somewhat of a wide variance of opinions among the committee members, sir.

Mr. GRIFFITH. Thank you.

Mr. Alexander?

Mr. ALEXANDER. Thank you. The question of whether to prove cargo first, if you will, before putting people on top, I certainly agree with that in terms of demonstrated reliability. Those cargo systems that are being developed are being developed right now and those will fly many times before people are put on those rockets or any new system goes on an Atlas V which already has a demonstrated reliable launch record. The question of whether cargo has delivered, you know, the programs has not been completed yet to first flight. They have not had their demonstration flights yet. As Mr. O'Connor said, every space program seems to have cost growth and schedule risk, or schedule drift, if you will. I would put the record of those cargo demonstration programs up against the record of government space program developments in terms of cost growth and schedule risk, and I think they would compare very favorably. So whether they have met all their milestones exactly as they originally planned four years ago, I am not the expert to speak to that but they are certainly progressing well as evidenced by the fact that NASA is paying on those milestones and is in agreement that things are progressing well. So I do believe that those programs are functioning well. I believe that, you know, demonstrated launch vehicles and cargo missions will happen before crew missions happen, and again, as I said before, the longer we wait to start that process of crew activities or commercial crew activities, the longer it will take us in terms of shortening any gap or when we actually would be able to deliver that service.

Mr. GRIFFITH. Thank you, Mr. Alexander.

RISK ASSESSMENT: COMMERCIAL VEHICLE

Dr. Fragola, are you involved in the risk assessment whether it be the risk assessment of a commercial vehicle for delivery of cargo or the development of a commercial vehicle for the delivery of our astronauts?

Mr. FRAGOLA. At this moment, I have no involvement in that. However, as part of the review, the independent review, I did look at the alternative launch vehicles, particularly Delta IV heavy. As part of the ESAS study, we did look at the Atlas V single core. By the way, it is important to point out as Mr. Alexander has mentioned, the Atlas with the 19 successes is a single-core vehicle with a rather limited payload capability to orbit as compared to the payloads that we are talking about on the Ares I. There is no doubt that the single-core vehicle would be more reliable than a triple-core Atlas but a triple-core Atlas doesn't exist today. We don't have an Atlas heavy. The option would be a Delta IV heavy and that was evaluated and seemed to be about a factor of two to a factor of three less safe than the Ares. But one of the things I wanted to point out, as I mentioned, immaturity is very important. One of the arguments against the Ares is, well, the first stage of the Ares is not equivalent to the SRB on the shuttles, it is a five-segment booster. I would point out that we are recovering the booster first stage. That is not going to occur on any of the commercial alternatives and so the learning we can get from inspection post flight is incredibly important to advancing the maturity of the vehicle and to proving that we have carried over the 255 successful launches of the SRB on the shuttle and the Ares I.

Mr. GRIFFITH. Thank you.

Thank you, Madam Chair.

Chairwoman GIFFORDS. Mr. Hall, please.

Mr. HALL. Madam Chairman, I think you will leave the record open for us to write and make inquiries if we need to. With that understanding, I will yield my time to Mr. Rohrabacher.

ARES, DELTA, ATLAS: COMPARISON

Mr. ROHRABACHER. Thank you very much. I just want to get into this thing about making some comparisons in terms of the alternatives that we have, and Dr. Fragola, I appreciate your comments.

I think we might disagree but I am really interested in learning from you on this because you know much more about it than I do. I understand that. But when you are suggesting to us that we have to look at the many uses that have been put through and the actual track record of the first stage of the Ares, that really doesn't count, does it? Because the system itself can't be certified as being reliable until the second stage, which has never even been built yet, is put into the system. Isn't that right? So with that type of analysis, there is not even a comparison between the Delta and Atlas in reliability because the Ares doesn't even have their second stage built yet, which the system will fail if the second stage doesn't work.

Mr. FRAGOLA. That is correct. The second stage is the risk driver and that is the reason why we chose a J2X system which has heritage both in the RS–68 engine and in the J2 engine and the J2–S engine. It is true that the stage and the engine as an integral sum has not been——

Mr. ROHRABACHER. You say risk driver, but that risk has already been assessed in terms of Atlas and Delta. We have no way to even assess whether that risk—what that risk is because we haven't even built the second stage——

Mr. FRAGOLA. Even——

Mr. ROHRABACHER. —to get the system that you are talking about.

Mr. FRAGOLA. Again, the equivalent payload, even on the Delta IV heavy, we would have to modify the second stage of the Delta IV heavy. There is no way we can get the payload that we get so we would have to have——

Mr. ROHRABACHER. Well, that is if you want a payload that big, but if you are having medium-sized payloads, it has already been proven.

Mr. FRAGOLA. If you were to decrease the requirements significantly down to the payload like Mr. Alexander has spoken to, then you would have to—you would be able to use the existing second stage——

Mr. ROHRABACHER. And you might want to have a few more launches rather than having to launch everything on one rocket. That doesn't—it doesn't make sense to me that you just have to have everything in a big payload carrier.

ORION SPACE CRAFT

Let me get to beside the rocket, and I only have a couple minutes left here. I would like to look at the actual spacecraft, the Orion spacecraft, as compared to the alternatives there as well, and again, I am not opposed to the Ares Orion system because I do believe in the moon project. I just think that if we try to do everything—the moon project has to be the same thing that we rely on for a low earth orbit. That may not be the best deal for the taxpayers and it may not be as reliable and it may not be as far so that we can bring it into play, but I understand Boeing—Boeing is in my district, and I seem to remember that they are developing this other spacecraft, and why is it that spacecraft—in terms of safety, is it more—is the Orion safer than what Boeing is presenting to us?

Mr. FRAGOLA. I guess I am not familiar with the particular Boeing spacecraft. I know some other spacecraft. Which one are you referring to?

Mr. ROHRABACHER. Well, it is in development right now. I understand that it hasn't been flown yet, but I understand that they are proposing this. Maybe I——

Mr. FRAGOLA. I can't comment on a design I haven't seen. I haven't seen that yet. If someone would present the design, I could look at it.

Mr. ROHRABACHER. And do the NASA people know anything about a Boeing proposal on this? So I am wrong then, I have been misinformed then that the commercial spacecraft companies are actually proposing a spacecraft that would be similar to Orion.

Mr. FRAGOLA. Well, we visited—similar to Orion, no, but we did visit a few people who had mockups of vehicles, but mockups of vehicles, we had them in ESAS four years ago. I mean, between that and a real design is a far way to come.

Mr. ROHRABACHER. And Mr. Alexander wants to mention something here.

COMMERCIAL CREW DEVELOPMENT PROGRAM

Mr. ALEXANDER. If I might, I believe that Boeing has teamed with Bigelow Aerospace to propose something under NASA's CCDev, or commercial crew development program. So that is at this point probably a concept——

Mr. ROHRABACHER. It hasn't actually been designed out and——

Mr. ALEXANDER. Right. They were one of the, you know, finalists for the Orion Crew Exploration Vehicle. Lockheed Martin ended up winning that program. I am sure that they have—their current design has a lot of heritage to what they were proposing for Orion but they were not the winner.

Mr. FRAGOLA. By the way, we saw that vehicle and that vehicle's design requirement requires you to rendezvous and dock within the first orbit in order to meet the payload, and that means that if you don't have proper rendezvous and you don't dock the first time, you deorbit, and Bigelow was willing to accept that because he was a commercial enterprise, but to do that on the station, I don't know that that's something that is prudent. If he does that, he limits the payload, limits the design. He also doesn't have to carry the things to sustain the crew for two or three orbits and that significantly reduces the mass of the——

Mr. ROHRABACHER. Thank you very much.

Thank you, Madam Chairman.

Chairwoman GIFFORDS. Thank you, Mr. Rohrabacher.

Ms. Edwards.

TRAINING FOR COMMERCIAL SPACE OPERATIVES

Ms. EDWARDS. Thank you, Madam Chairwoman. I just have a question and it goes to the testimony that you presented, General Stafford, with regard to training and your indication of how involved and important it is for the crew to really be involved in training that simulates off nominal conditions and also, you know, the number of hours that are spent with regard to safety in every detail. And so I wonder if you could actually speak to what you might identify as some of the challenges presented for training with commercial space operations.

Lt. Gen. STAFFORD. Ms. Edwards, to launch, rendezvous and then dock with the International Space Station, you would have, you know, working with the spacecraft simulator and mockups and then you also have integrated simulations with the mission control center that, you know, has control of the International Space Station. So you would have to go through the contingencies and so it would be a whole series of issues and that would start with a whole series of just to start with, using the launch abort system, the recovery, what action the crew would take, egress from it. And so also on these vehicles as they are being built, we are talking, I think, approximately, Ms. Edwards, two and a half flights per year, if I am correct, that the crew would probably be there at the factory when the spacecraft was being built too to understand it. But also in the simulations, it would be just repeat simulations and there is a profile for this and it requires really hundreds of hours.

Ms. EDWARDS. And do you think that that profile changes in any respect with what are essentially sort of off, you know, outside of NASA operations? And I also wonder if Mr. Alexander could speak to this question.

Lt. Gen. STAFFORD. Well, if it is outside of NASA operations, I would assume it would not go to the ISS because the requirements, you know, you have to go to rendezvous and dock with the ISS, a strict number of requirements. In fact, I was involved with some of that, having worked with the investigator with the Progress colliding with the Mir there on the Shuttle-Mir program then. So I think NASA would be involved there, and then you have, you know, particularly the commander and the pilot would have to be deeply involved and go through this and maybe people just along for the payload specialist or mission specialist for the ride would not have to undergo near that many but the one that is the commander and the pilot would definitely have to undergo hundreds of hours on that.

Ms. EDWARDS. Mr. Alexander?

Mr. ALEXANDER. Certainly a rigorous testing program and training program would be instituted for any commercial crew mission, whether it is a commercial mission just to low earth orbit or whether it is carrying NASA astronauts to the space station. So obviously everybody on board the vehicle is going to have to go through a rigorous training program, and certainly the pilot and commander would be much more rigorously trained than anybody that is just simply a participant on the flight.

I think in a broader context, you know, right now for any U.S. human spaceflight mission throughout our history, it has been a mix of government through NASA and industry, U.S. industry, building things, and the relationship has been one of a seamless, integrated relationship between NASA and industry, you know, a certain contractual environment. What we are talking about for a commercial crewed program that would fly NASA astronauts is still going to involve an intimate relationship between NASA and industry. Some of that relationship will change based on historical patterns. But it is certainly not one without the other, and I think it would be a mistake to assume that from a commercial perspective we expect to develop something, throw it over the transom and have NASA just accept it. NASA is going to be there every step of the way. They are going to be intimately involved and that certainly will be true for training of NASA astronauts but will also be true in the design, testing and production processes.

Ms. EDWARDS. So you don't envision any significant change to training protocols and requirements with a venture towards commercial operations?

Mr. ALEXANDER. I am not an expert on what those are today but there would certainly be rigorous training and there would certainly be agreement between NASA and the private sector about how that is going to happen and what is expected such that by the time a NASA astronaut is on board that vehicle, they are not only capable of flying it and capable of flying it in off nominal conditions and abort scenarios but that NASA at the highest levels all the way up to the Administrator and through Bryan O'Connor have the confidence in that system and the overall system capability including the people involved.

Ms. EDWARDS. Thank you, Madam Chairwoman.

Chairwoman GIFFORDS. Thank you, Ms. Edwards.

Ms. Kosmas, please.

SOYUZ SPACE CRAFT: CONCERNS MOVING FORWARD

Ms. KOSMAS. Thank you, Madam Chairman.

I wanted to chat with you all a little bit about the Soyuz that is intended to be used during the gap. I know, Mr. O'Connor, you spoke earlier about the history and the fact that not that much combined testing was done early on and that we made a decision as a Nation to send an astronaut anyway. But I think we are a little more enlightened now perhaps. As you know, following retirement of the shuttle, NASA is planning to rely solely on the Soyuz for astronaut transportation to and from the International Space Station, and this will probably be, from discussions we are having right now, for at least five years. So I would like to ask, General Stafford, you can answer it or Mr. O'Connor, last year the Soyuz experienced a few rough landings due to malfunctions, and can you discuss NASA's assessments following these incidents whether they were involved in the assessments following the incidents and the decision to continue to use the Soyuz? The other question which I will go ahead and ask now is, are we now—is the Soyuz now required to meet our U.S. standards for quality, safety, environment, wages of workers, financial accountability and engineering practices? So are they accountable to us in the same way that we would expect our commercial operations to be or that we would expect NASA itself to meet? I would appreciate if you could address that since it does appear that that is our alternative during the five years. General?

Lt. Gen. STAFFORD. Thank you, ma'am. As the chairman of the ISS Advisory Committee, we meet with our Russian colleagues at least twice a year and they have conference calls once a week concerning issues that would arise, and on that the Soyuz first flew in 1967. There have been two fatalities, one in 1967 and one in 1971. Since 1971 they have had 100 percent reliability. The basic first stage flew 52 years ago. The second stage in the Soyuz has been—is 42 years old. Since 1971 they have had 100 percent success. They did not meet all of our criteria. In fact, I am the only one on the committee here who has been in the Soyuz and I did that first one on the Apollo-Soyuz and we had them change a couple of their systems before we would fly with them and there has been follow-up since then, and I think Mr. O'Connor has outlined the fact of what they do with their safety and they are very attuned to it, and we are completely informed about that. As far as the two reentries on the delay of the service module, the separate and all that, they have taken into account, explained that, and so to me, it should be a situation that is solid again. I would rather have us fly on our spacecraft, ma'am, as soon as possible and if we had the budget we could do that.

Ms. KOSMAS. Mr. O'Connor?

Mr. O'CONNOR. Ms. Kosmas, we were quite concerned with these landings. In fact, Peggy Whitson was in one of those and it was a pretty interesting ride for her, and would be for anybody, and so we offered to help the Russians in their investigation. They put together a commission to take a look at it. General Stafford and his counterpart in Russia have a committee that oversees the safety of the Soyuz flights and they were interested. We were all asking questions. We did our own independent assessment of what we thought might have happened based on what we know about Soyuz' design and we compared notes with the Russians. In the end, they didn't get to the root cause the way they wanted to but they fixed all the possible things that could be the real root cause of this thing and they fixed those things to our satisfaction. They shared a lot of information with us, way more than they used to in the old days. There are some times when we and the Russians do not agree on something like, for example, the relative risk of some issue that has come up, but by and large they are very open, and when we don't agree with one another, we lean back on their demonstrated reliability, the quality of their workforce and the relationship our engineers have with theirs over a period of about 15 years now.

As for how we are planning to work with them in the future, we don't retroactively assign all of our human rating or any other kind of requirements on the Russians to participate with them as partners. We have an MOU with them. We have signed up to extend the MOU to fly our astronauts and those other astronauts from Japan, Canada and Europe who depend upon us for transportation. It is the Russian transportation that we will be providing for them as well. So we take them under our wing. We take our responsibility very seriously.

Ms. KOSMAS. Thank you. Unfortunately, the time is up.

Chairwoman GIFFORDS. Thank you, Ms. Kosmas.

Because we have a situation where we have time yielded to Mr. Rohrabacher, we actually now will go back to Mr. Rohrabacher, but I would like to introduce Ken Bowersox, an astronaut who has experience in both shuttle and Soyuz. It is good to see you today, sir. Welcome to our Committee.

Mr. Rohrabacher.

ADDRESSING THE GAP IN HUMAN SPACEFLIGHT

Mr. ROHRABACHER. Thank you very much, Madam Chairman, and we are in a little time bind here and I will try to be as quick as I can. Let me get to some fundamental issues here.

The basic challenge that we are facing is to close the gap that will be created when the shuttle is grounded as soon as possible and with as less risk as possible, and that is the challenge that we have. The challenge isn't going to the Moon. Right now the challenge we face is closing that gap. In terms of servicing the space station and low earth orbit, will the Delta system and the Atlas system, those rockets as they are now configured, will they be able to lift the payload necessary to deliver either a payload or crew to the space station or we will have to reconfigure those rockets? Anybody?

Mr. ALEXANDER. Absolutely those vehicles as they are designed now have the performance capability to take a capsule for people or cargo to the space station.

ARES

Mr. ROHRABACHER. Okay. When it comes to Ares Orion, they need to have something else that is developed and which is actually invented or, so to speak, a second stage or that system cannot deliver a capsule to the space station. Is that correct?

Mr. FRAGOLA. If it were the Orion capsule, it could not do that. For a degraded with payload that is much less than Orion and we would do it on a single-core Atlas, we would have to use probably an Atlas 431, which includes three solid rocket boosters wrapped around a central core, and I doubt that that would be able to pass snuff on safety because in the OSP days when Bowman did his report, comprehensive report of alternatives, they showed that wrapping solids around a liquid core is——

Mr. ROHRABACHER. Okay, but I am not talking about Atlas here. I just want to get the information about the Ares. We are going to have——

Mr. FRAGOLA. The Ares payload is significantly better than any of those alternatives.

Mr. ROHRABACHER. Okay, but it depends on developing a second stage that doesn't exist.

Mr. FRAGOLA. You would need a second stage for the Delta IV heavy as well to carry the payload. If you changed the payload or you changed the——

DELTA IV AND ATLAS

Mr. ROHRABACHER. Does the Delta IV—you are saying that the Delta IV cannot carry a payload to the space station without something new being put onto the Delta IV? I am trying to get at——

Mr. FRAGOLA. Yeah, for the Orion spacecraft on the Delta IV heavy, we would need a new upper stage. We would either have to four RL–10s or——

Mr. ROHRABACHER. We just heard the testimony from Mr. Alexander——

Mr. FRAGOLA. He is speaking of a much smaller payload.

Mr. ROHRABACHER. Well, listen, I am not talking about—you know, maybe we have to fly more missions to get the same level of payload. I am just talking about getting an actual payload to the space station. You might have to—it might actually be less risky to fly three Delta missions there with a rocket that currently we have than to rely on a rocket that has a heavier lift but you have to build a whole new second stage which may or may be able to be built. Until that thing flies, we don't even know if it is going to function.

Mr. FRAGOLA. I would respectfully suggest that history shows us that the first-stage problem is the serious problem, and on the Delta 431, which is the only single core that can carry the payload that Mr. Alexander is talking about, you would have not only a single core but you would have three solid rocket boosters, and the Delta II accidents and the Delta 34D accidents show how important the interaction between the solids and the liquids are in a survivable condition. You would create a condition if you lost the solid, that would engage the——

Mr. ROHRABACHER. I have only got a couple more seconds. But the Delta—from my understanding, the Delta and Atlas have a very good track record, and what we are saying is, we have a track record to actually get things to the station, close that gap as compared to an Ares. If our strategy is to depend on that, it is to depend on a second stage that hasn't been built yet, and I will have to say from my experience, any time you don't have a piece of technology that is built and functioning, you can have the schedule go way back and the costs go way up so we wouldn't be able to close that gap.

Mr. HANLEY. And that is exactly why—you mentioned Boeing earlier.

Mr. ROHRABACHER. Yes.

Mr. HANLEY. That is exactly why we have Boeing on contract to be producing the upper stage for Ares because they have the corporate knowledge and the heritage in producing such systems of similar scale and they are bringing—doing a fantastic job bringing their expertise——

Mr. ROHRABACHER. It was a good decision to take Boeing——

Chairwoman GIFFORDS. Mr. Rohrabacher, we only five minutes left in the vote so I am going to have to cut you off.

Mr. ROHRABACHER. Thank you very much.

Chairwoman GIFFORDS. Mr. Hill, my apologies. Okay. We are coming down to the minute. We are going to run over. I want to thank our witnesses today. It was absolutely brilliant testimony. I think we learned a lot. This won't be the first time that we address safety. We will come back to this because it is so critically important.

You know, I am sorry Mr. Hall can't be here for the end because I really believe what he said initially is so compelling and really reflects the sentiment of the Congress. We are strongly committed to provide a safe way for our astronauts to go to space and to travel back, and I have to say that I find the level of safety that has been planned for Ares and for Orion and the steps being taken to build safety into this Constellation program from the very beginning to be something that we have been proud to support for the last four years. While I continue to have an open mind, I look to the testimony of Mr. Marshall provided and I believe I quote you here, "The ASAP believes that if Constellation is not the optimum answer, than any new other design system has to be substantially superior to justify starting over." Based on what we have heard today, and there is more in your written testimony, I see no justification for a change in the direction on safety-related grounds. Instead, I am in fact impressed with the steps that have been to infuse safety into Constellation. It is something that of course we are very proud as a country we have been able to achieve this.

That being said, I don't intend, and I hope that people don't think that is a competition of commercial versus NASA. It is simply not that. We are all really excited and welcome the growth of new commercial space capabilities in America. Like Mr. Hanley, I too want to go to space and welcome the opportunity to do that someday, not for $30 million but maybe if the cost comes down. But currently I do not see those capabilities as competition with, as Mr. Alexander talked about, but rather complementary to our government systems that are currently under development. Whatever the Congress may decide to do with the question of additional incentives to the commercial space industry, of course, in this time of constrained budgets is something that really concerns all of us and this is why this discussion today has been so important. It is a question that needs to be decided on its merits, again, not on passion, not on what ifs but the actual reality of what is achievable and what can be documented. This is not a substitute for a continued commitment to the Constellation system that offers incredibly the safety benefits that we have heard in the testimony today.

So thank you, gentlemen, for being here and to the Members of Congress, of course, for being here. With that, I will bring this hearing to a close by stating that the record will remain open for two weeks for additional statements from the members and for answers to any follow-up questions that the Subcommittee may ask of the witnesses. The witnesses are now excused and the hearing is now adjourned. Thank you.

[Whereupon, at 12:30 p.m., the Subcommittee was adjourned.]

Appendix:

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Mr. Bryan O'Connor, Chief of Safety and Mission Assurance, National Aeronautics and Space Administration

Questions submitted by Chairwoman Gabrielle Giffords

Q1. In your prepared statement, you cite that NASA is beginning development of a more concise set of human rating technical requirements applicable to NASA developed crew transportation systems as well as commercially-developed crew transportation systems or use by NASA.

- *When do you envision these more concise human rating technical requirements will be defined so that commercial stakeholders can understand NASA's needs?*
- *Is solely meeting these technical requirements the litmus test NASA should use to determine if a commercial transportation system is safe for its astronauts to use?*

A1. NASA has formed a team to develop an implementation plan for human rating of commercially-developed crew transportation systems. This plan is based on NASA's approach to safety risk management and the existing Agency human rating philosophy. This plan will clarify NASA expectations, including technical requirements, and will be derived from: NASA Procedural Requirements 8705.2 (Human-Rating Requirements for Space Systems); Space Shuttle Program 50808 (ISS to Commercial Orbital Transportation Services Interface Requirements Document); and, other existing NASA requirements documents such as NASA Directives, NASA Standards, NASA adopted standards, the Exploration Architecture Requirements Document, the Constellation Architecture Requirements Document, and the Constellation Human Systems Integration Requirements.

NASA released the preliminary plan using a NASA Request For Information on May 21, 2010. Responses were due on June 18, 2010 and NASA is in the process of reviewing and evaluating the responses. NASA plans to finalize the Commercial Human-Rating implementation plan in time to support an open-competition when NASA pursues the development phase of commercial crew transportation systems.

Meeting NASA Human-Rating requirements is an important part of the overall process but not the sole test NASA will use to determine if a commercial transportation system is safe for NASA astronaut transportation. Any system destined to operate in the proximity of the ISS will be subject to the ISS "Visiting Vehicle" requirements, for example.

NASA will define, as part of this plan, the appropriate level of ongoing government visibility into the development, testing/engineering analysis, production and operation of all launch vehicles and spacecraft that carry NASA astronauts. NASA will also define its role in hazard and risk analysis/acceptance, as well as design and operational certification and flight readiness.

Q2. The Shuttle's operational costs have declined in the past few years.

a. Do lower operational costs necessarily mean less safety?

b. What lessons learned from the way NASA is operating the Shuttle may prove useful to how your office will oversee the safety of future space transportation system, be they government or commercially-provided?

A2. Although the overall annual Shuttle budget has declined over the past few years, it should not be interpreted that the decline is in the "operational costs" of conducting Shuttle missions.

After the Columbia accident in 2003, the Shuttle Program budget was significantly increased as NASA pursued parallel paths to address findings and recommendations of the Columbia Accident Investigation Board. The related costs for design, development, test and certification peaked in the 2004–2005 timeframe, and have gradually declined since.

As we approach the retirement of the Space Shuttle Program, NASA is gradually closing out the Shuttle Program's production capabilities as the last needed hardware and subsystems are making their way through the production pipeline. This has led to a further reduction of cost.

These cost reductions have not and will not impact the focus on safety by the Program for the remaining flights.

Once NASA has developed a strategy for acquisition of any new launch, entry, and/or emergency deorbit capability or service, the Agency must define its own role in ongoing management oversight and technical insight, including certification of the design and operation, and readiness of the team for flight, as well as ongoing role in problem resolution, sustaining engineering, hazard and risk analysis/acceptance. These decisions will be based on a number of factors, most stemming from hard lessons learned during Apollo 204, Challenger and Columbia mishap investigations and recovery. Examples include: a respect by all involved for the inherent risks in human spaceflight, not only in early development phases, but throughout the lifecycle; the need for rigorous checks and balance between the developer and the “owner” of the technical requirements (Technical Authority); the need for technical excellence among the development and assurance work force, the need to include flight crew in system development as well as flight test operations safety-critical decision-making; the necessity of continually challenging past assumptions and engineering models as part of the ongoing risk management process; and, the importance of clear roles and responsibilities and good communications in all directions as part of a healthy safety culture.

Questions submitted by Representative Pete Olson

Q1. Please explain with examples if possible. how NASA uses its human-rating requirements to tailor the design of a crewed space system such as Ares and Orion?

A1. NASA’s Human Ratings Requirements document (NPR 8705.2B) applies to the integrated flight/ground system, and is based on three key principles:

1) Human-rating is the process of designing, evaluating, and assuring that the total system can safely conduct the required human missions.
2) Human-rating includes the incorporation of design features and capabilities that accommodate human interaction with the system to enhance overall safety and mission success.
3) Human-rating includes the incorporation of design features and capabilities to enable safe recovery of the crew from hazardous situations.

For instance, requirements associated with the first principle drive a considerable focus on human factors aspects of the design, such as proper layout of cockpit displays and controls, and environmental factors such as adequate crew cabin temperature and humidity.

Separately, requirements associated with the third principle stipulate that certain abort and or escape capabilities be present. To implement this requirement, significant effort has gone into prelaunch and post landing emergency egress capabilities and the design of a launch abort system which would be used to pull the crew capsule away from the launch vehicle and allow the crew to return to Earth should a catastrophic event occur during launch. In light of the Presidential direction for FY 2011, it is worth noting that the lessons that NASA has learned from all past and present systems pertaining to human rating with be utilized, to the best extent practicable, in the development of any future vehicle.

Q2. If the human-rating requirements are the top level requirements, how would potential commercial providers gain the necessary insight to design a system that meets NASA’s requirements? Similarly, how did NASA get comfortable enough to finally certify the Russian Soyuz for human space flight?

A2. NASA has formed a team to develop an implementation plan for human rating of commercially-developed crew transportation systems. This plan is based on NASA’s approach to safety risk management and the existing Agency human rating philosophy. This plan will clarify NASA expectations including technical requirements, and was derived from NASA Procedural Requirements 8705.2 (Human-Rating Requirements for Space Systems); Space Shuttle Program 50808 (ISS to Commercial Orbital Transportation Services Interface Requirements Document); and, other existing NASA requirements documents such as NASA Directives, NASA Standards, NASA adopted standards, the Exploration Architecture Requirements Document, the Constellation Architecture Requirements Document, and the Constellation Human Systems Integration Requirements.

NASA released the preliminary plan using a NASA Request For Information on May 21, 2010. Responses were due on June 18, 2010 and NASA is in the process of reviewing and evaluating the responses. NASA plans to finalize the Commercial Human-Rating implementation plan in time to support an open-competition when NASA pursues the development phase of commercial crew transportation systems. Meeting NASA Human-Rating requirements is an important part of the overall process but not the sole test NASA will use to determine if a commercial transportation system is safe for NASA astronaut transportation. Any system destined to operate in the proximity of the ISS will be subject to the ISS "Visiting Vehicle" requirements, for example. Other considerations are demonstrated reliability, the extent and quality of the developer's design, test and evaluation processes as well as their production and operations activities.

NASA will define, as part of this plan, the appropriate level of on-going government visibility into the development, testing/engineering analysis, production and operation of all launch vehicles and spacecraft that carry Agency astronauts. NASA will also define its role in hazard and risk analysis/acceptance, as well as design and operational certification and flight readiness.

The first step in building confidence in Russia's human spaceflight in the early 1990's was to review lessons from the Apollo Soyuz program. Then NASA worked closely with the Russian Space Agency, now ROSCOSMOS to develop technical and management relationships and to understand each partner's roles and responsibilities for safety in the program. Before NASA began flying NASA astronauts on the Russian Soyuz, NASA performed several reviews of the Soyuz design, manufacturing, operations and quality and safety process. Based on these reviews, the trust stemming from our government to government relationships, as well as the long operational history of the Soyuz (rocket, crew capsule and ground systems), NASA developed the confidence to declare the Soyuz system acceptable for US astronaut participation. In preparation for potential use of the Soyuz design as a U.S. Space Station Freedom crew rescue vehicle, and then later in preparation for the joint Shuttle-Mir activity, NASA technical experts, including senior safety engineers, spent a significant amount of time talking with Apollo-Soyuz veterans, visiting with current Russian counterparts, and reviewing the long history of Soyuz, Salyut, and Mir operations in an effort to understand the Russian approach to human spaceflight safety. From this they were able to determine acceptability by equivalence to, if not compliance with, NASA technical standards. In March 1995, Norm Thagard became the first U.S. astronaut to launch on the Soyuz. He and the other five astronauts who spent time on Mir used the Shuttle for subsequent transportation, but they all received training in Soyuz as their primary escape system. The next American to launch on a Soyuz was Bill Shepherd, the Commander of the first Space Station increment in October 2000. Since then, 14 different NASA astronauts have flown on Soyuz, bringing the total NASA astronaut trips to 14 up, and 13 down, several of which were made during the post-Columbia Return-to-Flight timeframe. With over 15 years of joint operations NASA has gained confidence in the Russians systems and operations, as well as their design and development philosophy, including not just dependence on system reliability but on crew escape and on their extensive system and subsystem testing.

NASA has not certified, and does not intend to "certify," the Soyuz for human space flight relative to all NASA's technical requirements. NASA continues to approve or clear its participation in each flight by maintaining knowledge and insight into the on-going Soyuz program, formally approving NASA and NASA-sponsored crewmember participation in its own Flight Readiness Review process, and by participating in the Russian General Design Review process, which is similar to the Agency's Flight Readiness Review process. Additionally, since 1995 a joint Russian and NASA committee, the Space Station Advisory Committee (Stafford-Anfimov) advises both agencies on the operational and safety status for each Soyuz flight.

Q3. Since Crew Escape Systems, including emergency detection and launch abort systems, should be developed in conjunction with the launch vehicle, how could NASA evaluate the overall safety of an as-yet-to-be developed launch vehicle whether provided by a COTS provider, United Launch Alliance, or an international partner?

A3. As suggested by the question, the evaluation of abort system effectiveness, and human rating in general, requires an integrated analysis of launch vehicle, crew capsule, crew, and the abort system itself. Any launch vehicle has to be designed to provide critical vehicle status and abort triggers to notify the crew vehicle and launch escape system that an abort is required or to allow the crew to make an abort decision. The design needs to take into account the launch vehicle failure modes and the timely detection of these failures. Transportation system developers would be required to design the integrated vehicle to support the abort trigger requirements. The crew escape system would have to be designed so that it can reliably and safely pull the crew capsule from the launch vehicle given the failures and resulting environments during the critical portions of the launch vehicle's flight profile. An integrated safety analysis to review the specific implementation would be conducted to assure that effective crew escape capabilities are available to address critical failure scenarios of the integrated system.

NASA has spent considerable effort in doing this kind of analysis for the baseline architecture. Similar analyses will have to be performed for other concepts.

Q4. From the Safety and Mission Assurance perspective, would you elaborate on the potential to close the gap using EELV's, including cost information if available?

A4. NASA doesn't human-rate individual components or elements of a launch system, so in order to use an EELV that EELV would need to be human-rated in combination with all of the flight and ground elements needed to accomplish a specific reference mission. The EELVs in combination with these other elements (spacecraft, abort/escape/egress system, etc.) would need to be human-rated to ensure that collectively they provide a sufficient level of safety, and particularly allow for survivability of the crew during any potential hazardous situations.

In 2009, NASA commissioned a study performed by Aerospace Corporation to study the feasibility of human rating current EELVs. The study concluded that EELVs are "human-ratable," however the cost to do so is highly dependent on program requirements, specific interpretation of and compliance with NASA's human-rating requirements document (NASA Procedural Requirements 8705.2) and especially noteworthy the integration of the EELV design with other elements of the system. In addition, the study found that the gap between Shuttle retirement and availability of a new crew transportation system to ISS would not be reduced from the then-current Constellation target milestone of March 2015 initial operating capability.

Q5. Since a significant portion of launch failures are due to human error it is critical to have a strong safety culture. The Columbia Accident Investigation Board reiterated again the importance of a strong safety culture. Would a shift to commercially provided low-Earth orbit launch vehicles disrupt that culture at NASA? Could that be cause for concern?

A5. Depending on the acquisition approach, contracting with industry for a new ISS crew transportation system could represent some changes in NASA's traditional human spaceflight processes, including its interactions with industry. NASA will "own" major NASA-related safety requirements (visiting vehicle and human rating), and will establish an appropriate forum for verification that the system has met them. To the extent that NASA retains accountability for the safety of its employees and contractors (crewmembers), it will play a role in technical oversight/insight, as well as hazard analysis, and risk assessment and acceptance. These processes and relationships, however, are only a part of a strong safety culture, the remaining aspects being all about communications in all directions. Especially important will be the establishment and maintenance of a strong effective dissent and appeal system on both the commercial and government side of the relationship. NASA is committed to preserving a strong safety culture regardless of the acquisition approach.

Questions submitted by Representative Marcia L. Fudge

Q1. In your prepared statement, you cite that NASA is beginning development of a more concise set of human rating technical requirements applicable to NASA developed crew transportation systems as well as commercially-developed crew transportation systems or use by NASA.

- *When do you envision these more concise human rating technical requirements will be defined so that commercial stakeholders can understand NASA's needs?*
- *Is solely meeting these technical requirements the litmus test NASA should use to determine if a commercial transportation system is safe for its astronauts to use?*

A1. NASA has formed a team to develop an implementation plan for human rating of commercially-developed crew transportation systems. This plan is based on NASA's approach to safety risk management and the existing Agency human rating philosophy. This plan will clarify NASA expectations including technical requirements, and will be derived from: NASA Procedural Requirements 8705.2 (Human-Rating Requirements for Space Systems); Space Shuttle Program 50808 (ISS to Commercial Orbital Transportation Services Interface Requirements Document); and, other existing NASA requirements documents, such as NASA Directives, NASA Standards, NASA-adopted standards, the Exploration Architecture Requirements Document, the Constellation Architecture Requirements Document, and the Constellation Human Systems Integration Requirements.

NASA released the preliminary plan using a NASA Request For Information on May 21, 2010. Responses were due on June 18, 2010 and NASA is in the process of reviewing and evaluating the responses. NASA plans to finalize the Commercial Human-Rating implementation plan in time to support an open-competition when NASA pursues the development phase of commercial crew transportation systems.

Meeting NASA Human-Rating requirements is an important part of the overall process, but not the sole test NASA will use to determine if a commercial transportation system is safe for NASA astronaut transportation. Any system destined to operate in the proximity of the ISS will also be subject to the ISS "Visiting Vehicle" requirements, for example.

NASA will define, as part of this plan, the appropriate level of ongoing government visibility into the development, testing/engineering analysis, production and operation of all launch vehicles and spacecraft that carry NASA astronauts. NASA will also define its role in hazard and risk analysis/acceptance, as well as design and operational certification and flight readiness.

Q2. The Columbia Accident Investigation Board (CAIB) recommended the establishment of an independent Technical Engineering Authority responsible for technical requirements and all waivers to them. In response, NASA created the NASA Engineering and Safety Center's (NESC) which operationally falls under the responsibility of your office. How has that independent center enhanced the safety of human space flight?

A2. In response to recommendations from the CAIB, NASA formalized Technical Authority (TA) roles for NASA's Safety and Mission Assurance, Engineering and Health and Medical organizations establishing clear authority and responsibilities related to the technical requirements established by the TA organizations and waivers to those requirements.

The TAs are a key part of NASA's overall system of checks and balances and provide independent oversight of programs and projects in support of safety and mission success. Individuals fulfilling the TA roles are embedded in their respective technical cadres and organizations across the Agency, and are continuously engaged in programmatic decision-making processes. They ensure that all opinions are heard and engage with line management to ensure that the right technical decisions are made with respect to requirements, non-compliances, hazards, critical items, as well as ensuring work is performed to a high standard.

The NESC was formed in response to CAIB criticism of the safety organization's lack of technical depth. Its mission is to perform value-added independent testing, analysis, and assessments of NASA's high-risk projects to help ensure safety and mission success. The organization has established a strong set of processes, technical leaders and communities of practice across the Agency and access to key technical experts and facilities outside of NASA to allow rapid response with the best possible technical capability to the Agency's most critical problems. In a typical year, the NESC performs in excess of 50 independent assessments for a variety of customers, including, but not limited to, the Agency's SMA organizations.

The Technical Authorities and the NESC operate across all of NASA but are particularly important in addressing problems which arise in connection with human space flight. The totality of the contributions is too great to catalog here, but two examples are illustrative.

Between the time of STS–114, the return to flight after Columbia, and the final preparations for the launch of STS–120 in the fall of 2007, anomalies with the Reinforced Carbon Carbon panels used on the wing leading edges had come to light. All panels show cracking and crazing after exposure to high temperatures with damage thresholds established for repair or replacement but there was new test data potentially indicating the need to repair or replace panels not previously suspect.

The NESC was asked to quickly establish an independent team to assess the problem in parallel with the ongoing work being performed by the project team. The NESC team performed a great deal of high caliber and ground breaking technical work in a short time and recommended both a measurement methodology and quantitative threshold. The processes established in support of the Technical Authority model for the flight readiness reviews and leading to the Certification of Flight Readiness ensured that the recommendations were fully considered and led to adoption of both the recommended flight worthiness criterion for the RCC and a longer term program to better understand the materials and utilize nondestructive inspection techniques in support of improved flight safety.

Data from the flight of STS–126 in November 2009 and post-flight inspection of the hydrogen flow control valves showed that a large piece of a valve poppet had liberated. This had never happened before in flight and raised significant safety of flight concerns for STS–119 since there were multiple scenarios leading to catastrophic failures during powered flight. The problem was extremely difficult and the first round of reviews could not establish a rationale and supporting data to allow a commitment to launch. In response, the Project team was augmented with engineering and safety and mission assurance personnel from across the Agency to establish and execute a combination of tests and analyses to establish the basis for a safety of flight assessment. The NESC brought its cadre to bear, both to directly support the technical teams and also to provide independent assessments in critical areas. Technical authority line managers were strongly engaged both to ensure that all possible resources were brought to bear but also that the many alternate technical opinions were appropriately heard and considered and that a flight rational could be established on a sound technical basis. As a result of an extraordinary quantity and quality of work done in a very short time, not only was a sound decision basis established for the safe launch of STS–119 but the understanding of the flow control valve failure modes and effects and non-destructive examination techniques were greatly improved. This in turn led to greatly improved processes and criteria for all subsequent missions and significant reduction in risk.

Q3. The Augustine Committee has done a commendable job of providing options and alternatives for the U.S. Human Space Flight program for consideration. However, changes to an ongoing development program carry the real threat of major adverse impacts on cost and schedule, increased risk and dislocations for the workforce. In this regard, please comment on the safety impacts of two potential changes discussed in the Summary Report: 1) Reducing Orion crew size; and, 2) Relying on commercial crew-delivery service rather than continuing the development of Ares 1.

A3. NASA looks at any significant change in architecture or performance requirements with an eye toward safety impacts. The decision to reduce the crew size from six to four had no direct or indirect adverse safety. The primary rationale for the Orion crew size requirement change was to simplify design activities and thereby reduce cost and schedule challenges while improving mass margins during the Program's early phases. Since the maximum crew size requirements were originally established at the Constellation Systems Requirements Review in 2006, Orion had been pursuing parallel designs for the Space Station six-person and the Lunar four-person configurations. Therefore, Orion's work included multiple designs for crew seat pallets and Environmental Control and Life Support hardware, and multiple analyses for consumables, stowage, and crew operations. By shifting to a common crew size configuration for the Space Station and lunar missions, Orion's team would be able to focus activities on a single design and analysis set rather than two parallel design efforts.

The maximum crew size reduction for Orion ISS missions actually had operational advantages that improve crew safety:

- The free volume for the crew's on-orbit activities and tasks could be increased by 20–25 cubic feet.
- The nominal and emergency crew egress capability would be improved.
- More stowage volume and mass could be made available for carrying mission equipment and bringing payloads and cargo to the ISS.

The President's budget "funds NASA to contract with industry to provide astronaut transportation to ISS as soon as possible, reducing the risk of relying solely on foreign crew transports." In response, NASA will use an acquisition approach appropriate to the criticality of and risk inherent in the mission. Included will be an acceptable mix of NASA technical requirements and industry practices as well as NASA technical insight and management oversight. These things, along with the design, support and demonstrated reliability of the transportation system, will allow NASA to determine when the system will be suitable to carry NASA (and International Partner) crews to the ISS.

Q4. One of the Augustine Committee findings is that investment in a well-designed and adequately funded space technology program is critical to enable progress in exploration. NASA's space technology budget has been severely reduced over time. Power, propulsion, in-space refueling, communications and a host of other technologies will be crucial for exploration. What safety-related considerations are associated with investing in such technologies?

A4. Without new technologies, human exploration of the solar system will likely be unaffordable and unsustainable. The safety implications of new technologies, however, must be evaluated on a case-by-case basis. While the use of new technologies can provide safety benefits, e.g., by eliminating risks in existing systems and through increasing safety margins, they also generally introduce risks due to immaturity of and unfamiliarity with such technologies.

These impacts must be assessed as part of design and operational trade studies. For example, technology development for in-space refueling must weigh the safety impact of designs involving an initial crew transportation system that fully relies on in-space refueling against a crew transportation system that can take advantage of in-space refueling after the refueling technology has been proven with robotic missions.

However, new technologies are not necessarily used to improve safety, and may instead be used to expand mission goals. For example, weight savings in one area might be used to increase science/mission payload or to increase propellant reserves or shielding. The investment in developing and integrating new technologies is essential to ensuring that our Nation's space program is engaged in innovations that will help NASA find better and safer ways to explore the solar system.

Questions submitted by Representative Dana Rohrabacher

Q1. In the Launch Services Program NASA has generally required that a launcher demonstrate multiple successful flights before being considered for use launching science payloads and satellites. In some cases, up to 14 successful flights of the rocket were required before being used to launch a "Class A" satellite. By contrast, the Constellation Program is currently planning (subject to review) only one full-up test flight before placing astronauts aboard the Orion/Ares I. I understand that these two parts of NASA—manned and unmanned—have different requirements and operate with different rules, but in both cases the overall mission success is a primary objective. Can you please explain how these two systems of evaluating launch vehicles have evolved so differently, what are the similarities, and in the above example how NASA's Constellation program can comfortably accept a plan that demands 92 percent fewer test flights than what was required for a satellite program?

A1. The most important factor in determining when it is appropriate to fly crewmembers on a new test vehicle is the level of confidence the team has in safely conducting the test. In the case where NASA validates the technical requirements, designs and manufactures the flight and ground systems, writes the launch commit criteria and flight rules, performs all number of ground tests and engineering analyses, and conducts the reliability, safety and risk analyses, it has arguably maximized its understanding of and associated confidence in the system. Based on this, the team decides when to conduct its first crewed flight test. As the distance between NASA and the design, development, manufacturing, and operations increases, so does the Agency's reliance on demonstrated reliability, and/or other government certifications (i.e. Russia's ROSCOSMOS or the U.S.'s Federal Aviation Administration). NASA has not come to a final determination on the number of test flights that would be required prior to sending NASA astronauts into space using the crew launch vehicle under the Program of Record.

Regarding the comparison with the LSP, NASA has a range of options available depending on the launch system's proven reliability, the value of the payload, and the certification status of the provider. In some cases, this program has little insight into, or oversight of, the commercial launch providers. In those cases, NASA requires a demonstration of 14 successful launches for certification of the launch vehicle for high value payloads. This certification option, which is rarely chosen, is predicated on an assumption of no prior knowledge about launch vehicle performance, and limited government oversight into the design and operation. Another option is to fly the NASA payload on a relatively new system with as few as three flights (two successes in a row), but with substantial NASA process requirements and insight into the contractor's design, engineering and operations processes. For lower value payloads with a higher risk tolerance, another certification category is available. It only requires one successful flight of the launch vehicle and a significant technical assessment.

NASA's ongoing human spaceflight program has established a host of safety and mission assurance activities including (subsystem) tests, verifications, and analyses, which would establish a level of confidence in the vehicle's performance prior to the full-system test launches. Decisions regarding the needed number of full-system test launches should account for these assurance activities.

Q2. John Marshall from the Aerospace Safety Advisory Panel (ASAP) said in his written testimony that, "more than two years into the COTS program, efforts to develop human rating standards for a COTS–D like program have only just begun and no guidance thus far has been promulgated. If COTS entities are ever to provide the level of safety expected for NASA crews, it is imperative that NASA's criteria for safety design of such systems immediately be agreed upon *and provided to current or future COTS providers." What steps is NASA taking to address this concern and develop a process that can be used by potential COTS–D competitors?*

A2. NASA has determined that human rating requirements will apply to any crew transportation systems used by the Agency to provide transportation to low earth orbit. Consistent with the President's plan to "contract with industry to provide astronaut transportation to the International Space Station as soon as possible, reducing the risk of relying solely on foreign crew transports . . ." NASA is using American Recovery Reinvestment Act (P.L. 111–5) funds to develop guidelines for acquisition and oversight/insight approach in FY 2010. NASA's approach to human-rating a transportation architecture for a specific mission starts with the initial design phase, and assumes all pertinent NASA standards and requirements are followed throughout the project. This task will define a minimum set of human rating requirements and consolidate them into a single product using a development team comprised of representatives from NASA's human space flight programs, NASA technical authorities, and the NASA Astronaut Office. In addition, NASA will define hazard and risk assessment processes and goals and thresholds to support risk acceptability decisions. NASA will seek the advice of interested industry stakeholders to refine the human rating technical requirements.

More specifically, NASA has formed a team to develop an implementation plan for human rating of commercially-developed crew transportation systems. This plan is based on NASA's approach to safety risk management and the existing Agency human rating philosophy. This plan will clarify NASA expectations, including technical requirements, and was derived from: NASA Procedural Requirements 8705.2 (Human-Rating Requirements for Space Systems); Space Shuttle Program 50808 (ISS to Commercial Orbital Transportation Services Interface Requirements Document); and, other existing NASA requirements documents such as NASA Directives, NASA Standards, NASA adopted standards, the Exploration Architecture Requirements Document, the Constellation Architecture Requirements Document, and the Constellation Human Systems Integration Requirements.

NASA released the preliminary plan using a NASA Request For Information on May 21, 2010. Responses were due on June 18, 2010 and NASA is in the process of reviewing and evaluating the responses. NASA plans to finalize the Commercial Human-Rating implementation plan in time to support an open-competition when NASA pursues the development phase of commercial crew transportation systems.

Q3. Dr. Fragola indicated during the hearing that a launch vehicle with a liquid core and solid strap-ons was likely to present a more dangerous, or a more difficult environment for crew escape in the event of a launch catastrophe. What is the reason for this, and does it apply evenly to shuttle derived concepts such as shuttle-C, or Jupiter Direct type designs? Further, it has been reported that pursuant to the Augustine committee report, NASA is studying the human rating of heavy lift vehicle concepts (or their derivatives) as potential Orion launch vehicles. Assuming any new Orion-carrying heavy lift vehicle would use a combination of liquid core with solid strap-ons, how does that affect the crew escape and Loss of Crew calculations?

A3. The reason that strap-on boosters in general represent a more difficult environment for crew escape in event of a launch catastrophe includes the following two factors. First, such configurations have failure modes that would more readily propagate from one booster to another, with the potential to lead to a more energetic post-accident environment. Secondly, there is a much greater potential for thrust imbalance, leading to greater aerodynamic stresses. These concerns apply to Shuttle-derived concepts.

A better understanding of the specifics and absolute values of the relative risks of the various configurations would require simulations of the post accident environment and system responses similar to those already performed on the Ares I configuration. If Orion and the launch abort system remain the same, it would be expected that in the heavy lift configuration the factors mentioned above would cause a higher risk to the crew than in the Ares I configuration.

At the same time, compared to side-mount options, this configuration would cause the crew to be further removed from the first stage, which would actually reduce risk to the crew due to failures of the solid/liquid first stage combination. The increased launch capability of a heavy lift configuration would further allow for modifications to Orion and the launch abort system that enhance crew survival capabilities.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Mr. Jeff Hanley, Program Manager, Constellation Program, Exploration Systems Mission Directorate, National Aeronautics and Space Administration

Questions submitted by Chairwoman Gabrielle Giffords

Q1. What is the basis of NASA's determination that the Ares I/Orion combination should be ten times safer than the Shuttle? How confident are you that you can achieve that level of safety?

A1. With regard to your questions about the current program of record, NASA's Constellation Program was developed with the goal of increasing astronaut safety tenfold relative to Shuttle missions based on two key directives:

- The May 2004 Astronaut Office Position on Future Launch System Safety, which stated that office's belief that an order of magnitude reduction of risk during the ascent phase of a crewed space mission was possible. This position was written with regard to the Orbital Space Plane booster selection, and in response to the Columbia Accident Investigation Report, and it serves as a goal for increasing system safety during this critical phase of flight.
- The Exploration Systems Architecture Study (ESAS) of November 2005, which suggested that ". . . crew missions to the ISS may be at least 10 times safer than the Shuttle . . ." While risk estimates for various phases of flight (e.g., ascent, docking, re-entry, landing) and spacecraft components (e.g., service module) are constantly undergoing review the Constellation Program's Loss-of-Crew (LOC) requirements were derived from the ESAS.

Probabilistic Risk Analysis (PRA) is a tool used to analyze system risks and understand a systems probability of problems and the magnitude of impacts due to the problems. Program managers use PRAs to assess designs in an effort to judge merits of technical trades. Additionally, NASA communicates risks to project, engineers and the outside world using PRAs. PRA numbers fluctuate over time as designs mature and system trades are accepted.

From the very beginning, Constellation has been committed to building an architecture that effectively balances the use of critical design commodities to achieve the optimal safety and mission success capability. Therefore, at the time of my testimony, NASA believed its ultimate goal of increasing safety tenfold via the utilization of the Ares I/Orion combination, while seemingly daunting, would have been achievable. However, based on current data, NASA believes the Ares I/Orion combination overall would be about five times safer than the Shuttle. These numbers, however, are averaged estimates and not the way that NASA calculates or tracks the PRA of specific vehicles.

In terms of Ares I/Orion, the current PRA for the integrated stack for the Ascent Phase shows a 1 in 1,877 probability LOC. It also greatly exceeds the challenging 1 in 1,000 LOC Ascent Phase requirement. This is due to both the projected reliability of the Ares I launch vehicle and a robust Launch Abort System. For the On-Orbit Phase, the current Constellation Program PRA results in a 1 in 521 for a 210 day mission. This phase is heavily dominated by the micrometeoroid and orbital debris risk to both vehicles. For the entry phase, as we have seen through history, is just as demanding as the ascent phase. Because of this, NASA has the same challenging 1 in 1,000 LOC requirement as for the ascent phase. Unlike ascent where there will be abort capabilities; there is no easy way to gain significant improvement for the entry phase. The risk is dominated by parachute and thermal protection system contributions. These systems are currently a priority for design improvements as well as a comprehensive test program.

In comparison, the purpose of the Shuttle PRA is to provide a useful risk management tool for the Space Shuttle Program to identify strengths and possible weaknesses in the Shuttle design and operation. Currently, the mean PRA for an entire Space Shuttle mission to the ISS (including the ascent, on-orbit and re-entry phases) is 1 in 89, with a range of 1:63 to 1:130 (representing the 5th and 95th percentiles). The equivalent PRA figure for Constellation is 1 in 406, representing a 4.6 factor of improvement over the Shuttle risk assessment for the equivalent 5 day docked ISS mission.

As with any PRA of a large, complex, and engineered system, the Shuttle PRA is developed for a defined scope, and reasonable engineering judgment is used to make assumptions where necessary. Therefore, limitations exist as to its use, and the per-mission ratio should not be seen as a single-point estimate, but merely the mean number in a range of risk. The PRA can be useful in comparing different systems (assuming they are calculated using similar bases), and not as an absolute risk number. For these and other reasons, it is difficult to compare Constellation risk estimates to the Shuttle PRA; NASA has a far higher level of knowledge about the Shuttle system and the PRA methodologies for operational systems are different from the risk estimation methodologies for systems in development.

Q2. You are having to human-rate the Constellation launch vehicle and spacecraft system. How involved a process is that? Is it simple compliance with a set of itemized requirements, or is it something more involved?

A2. Regarding human-rating, the launch of any spacecraft is a very dynamic event that requires a tremendous amount of energy to accelerate to orbital velocities in a matter of minutes. There also is significant inherent risk that exposes a flight crew to potential hazards. Through a very stringent human rating process, NASA attempts to eliminate hazards that could harm the crew, control the hazards that do remain, and provide for crew survival even in the presence of system failures.

Human rating is a process that involves more than a simple set of design requirements. The process intertwines with the acquisition process, starting with initial concept design and progressing through all phases of the program. Its progress is checked and reported to Agency management at each major acquisition milestone. It includes not just requirements compliance, but also consideration of hazards, failure modes, escape system effectiveness and limitations, failure tolerance, and other safety risks both in flight and on the ground. The requirements are all applicable mandatory standards used in designing and operating our most important unmanned mission systems, with the addition of human crew unique requirements dealing with life support, human factors, crew escape/abort and survivability. The scope and magnitude of the process is dependent upon the Agency's risk tolerance for the particular mission, as well as the complexities and hazards associated with the vehicle design and its assigned mission profile. As written, NASA's human rating process is structured specifically for NASA developed systems, where the NASA program manager is the design decision and risk acceptance authority, and the NASA Engineering, Safety and Mission Assurance, and Health and Medical Technical Authorities have cognizance of the associated standards and requirements. However, Agency policy allows some or all of its human rating process and requirements to be applied, as it sees fit, to systems developed by other organizations or entities as conditions for clearance to fly NASA or NASA sponsored crew/passengers.

For NASA developed systems, human rating certification includes: validation by the technical authorities that the design requirements are properly tailored to the program; verification that the design meets those design requirements (by ground test, analysis, and flight test as appropriate); and full-up flight demonstration of an appropriate level of system reliability prior to manned flight test and prior to full mission clearance. Finally, NASA human rates an entire system, including ground elements and operational procedures (fundamentally, anything about the flight or ground system that impacts flight crew/passenger safety). This means that it looks at integrated safety issues and accident scenarios, not just failures at the subsystem level.

Given that safety is NASA's first core value, the Constellation Program, had incorporated safety into the Constellation design process from the very beginning. In doing so, the Constellation program chose to tightly interweave the design and safety team members into the decision process, including Engineering, Safety and Mission Assurance and Health and Medical technical authorities, so that each have a role in the Agency's human rating process. The team has actively worked with the design engineers to provide expertise and feedback via various assessments and analysis techniques throughout the design maturation process.

Human rating a spaceflight system is not as easy as following one document. Instead, it is an intricate, continuing process, involving the translation of specific mission requirements into designs that can be built, tested, and certified for flight and an understanding of risks with mitigation approaches in place. Additionally, before any system can be human rated, it must meet all other Agency standards and requirements applicable to a specific mission and type of system. Therefore, part of the challenge to projects such as Ares I and Orion has been that there is currently no single document that spells out what they should do to receive a human rating certification from the Agency. In turn, this is partly why NASA is investing FY 2009 Recovery Act funds to develop a more concise set of NASA human rating technical requirements.

Although NASA does not yet have one consolidated document for human rating, the Constellation Program has depended heavily on NASA Procedural Requirement

8705.2B, in designing its spaceflight vehicles. This document is based on three key tenets:

1) **Human-rating is the process of designing, evaluating, and ensuring that the total system can safely conduct the required human missions**. The mission will have certain mission objectives and system performance requirements that must be met. The mission will also expose the crew to potential hazards that must be considered early in the design process. During the design process, a careful examination of the potential hazards and design features that prevent hazards—known as "hazard controls"—is undertaken. Hazard controls are features incorporated into the system during the design phase to prevent the occurrence of a hazard. These can take many forms such as incorporating redundant or backup systems and components, application of system margins to ensure function of the system even under the most extreme conditions, proper selection of technical standards for design and construction, and rigorous process controls from early material and component selection through final assembly and checkout operations. Mission objectives and performance requirements may need to be reevaluated to reduce the risk for human spaceflight missions. The balance between system performance and crew safety would be weighed among Engineering, Safety and Mission Assurance, and Crew Health and Medical technical authorities. The outcome of the design will be a balance between maximizing mission objectives while minimizing risk to the flight crew.
2) **Human-rating includes the incorporation of design features and capabilities that accommodate human interaction with the system to enhance overall safety and mission success**. This tenet includes all the aspects of flight crew performance necessary for the crew to successfully carry out their mission, without imposing undo risk to the flight crew. Crew situational awareness, crew commanding, cockpit display design and spacecraft environmental factors all are critical factors that affect a crewmember's performance. For example, proper layout of controls, adequate crew cabin temperature and humidity, and proper mission workload planning all factor into the crewmember's ability to safety operate the system and increase the likelihood of mission success. The same rigor and balance in design trades utilized in tenet one is applied also in tenet two to arrive at the best working environment for the crew that maximizes the probability of mission success, while minimizing the risk to the flight crew.
3) **Human-rating includes the incorporation of design features and capabilities to enable safe recovery of the crew from hazardous situations**. Launch of a crew has significant inherent risks, so even with all the care that goes into system design and development, the system must be designed to accommodate failure. Sometimes failure can be dealt with by designing redundant systems that would allow mission continuation. In some cases, however, mission continuation is no longer possible and steps must be taken to safely return the crew—an event that is usually referred to as a mission abort. In the case of a launch failure, an abort could involve an emergency return of the crew. The Orion vehicle, for example, will have a launch abort system which could be used to pull the crew capsule away from the Ares I launch vehicle and allow the crew to immediately return to Earth should a catastrophic event occur. An abort also can be an operational decision to stop the mission and return the crew if, for example a system has degraded to a point that mission continuation exposes the crew to an increased probability of a catastrophic hazard.

The President's FY 2011 budget request includes significant investments to spur the development of commercial crew and further cargo capabilities, building on the successful progress in the development of commercial cargo capabilities to-date. A key early step to enable commercial crew transport is establishing a concise set of NASA human rating technical requirements that would be applicable to NASA developed crew transportation systems for Low Earth Orbit (LEO) as well as commercially-developed crew transportation systems for use by NASA. NASA is investing Recovery Act funds to begin development of these requirements. A NASA team has completed an initial set of commercial crew human rating requirements documents and commercial human systems interface requirements document and the documents are currently in the preliminary review cycle. A Request for Information will be issued within the next few months to seek industry feedback on related human-rating documents. In addition to the human rating requirements, NASA is developing an insight/oversight model that will contribute to the safe flight and safe return of NASA crew members on commercial space vehicles. NASA's years of experience and lessons learned with respect to human rating of space systems will help shape future systems to be developed in as safe a manner as possible.

Questions submitted by Representative Pete Olson

Q1. Although the Ares I–X test flight was not an exact replica of the Ares 1, it involved a significant effort by the launch team to modify the facilities and develop the launch processing requirements and procedures to perform a successful test flight. In addition, Ares I–X was instrumented with over 700 sensors relaying information about the flight. To what extent do test flights improve safety and reliability by reducing overall risk? If adequate funding were available would more test flights allow you to accelerate the development and achieve an earlier crewed flight to shorten the gap?

A1. In general, a comprehensive flight test program is essential to understanding the integrated vehicle systems in the actual flight environment. Flight test provides engineers with the confidence in and understanding of the flight systems. Flight tests can and will reveal many of the "unknown unknowns" which remain hidden in analysis and subsystem (not integrated) testing, thus allowing engineers to solve problems before committing high-value payloads or crews to flight. Flight tests also enable engineers to better calibrate models so that they are more accurate in predicting worst case loads on the vehicle, responses of the vehicle's structure, and other parameters that ultimately affect final designs for safety,. Furthermore, flight tests enable retirement of risks that cannot be fully mitigated through ground testing only. Demonstrating factors such as vehicle controllability, abort effectiveness, and re-entry and landing performance under integrated real-world conditions must occur before crewed flight. Flight tests prove these and other critical systems are therefore essential to attaining an acceptable risk posture for crewed flight.

Even flight tests of vehicles that are not identical to the final operational configuration still provide valuable data, though for obvious reasons, the closer the test article can be to final configuration, the more useful the test results. For example, NASA's Ares I–X test flight afforded NASA the opportunity to collect data that would be used to refine computational models and subscale test techniques that would be used by Ares I, thus allowing reduction of conservatism incorporated into initial models. Other test events, such as the recent firing of an Ares first stage development motor, designated "DM–1", and subsequent static test firings, also contribute to analytical model validation and refinement. Such tests provide additional real data to anchor analytical models used to predict vehicle physics, such as thrust oscillations, specific to Ares I. While additional test flights for the program of record could help achieve additional risk reduction, NASA will ensure that all future cargo and crew systems adequately test all flight systems prior to operational use.

In terms of the Constellation Program, the addition of more test flights would not allow NASA to achieve an accelerated first crewed flight. Acceleration is not merely a funding matter; the potential for acceleration is also influenced by hardware development and system testing schedules, and NASA has reached the point where the development schedule for most systems could not be accelerated due to testing needs and limits on the ability to further accelerate procurements. The "long pole" in getting to human flight is completing the system qualification testing, and the associated procurements, fabrication, and assembly for the qualification vehicle and hardware. To be clear, flight testing is different than qualification testing. Qualification testing exercises hardware through the full range of conditions it might experience (such as maximum and minimum operating temperatures). Flight tests, on the other hand, validate integrated real-world performance at a single set of conditions. Additional flight testing would not accelerate the Constellation Program's development schedule asgiven the long pole lies with qualification testing.

Q2. Moving NASA beyond low Earth orbit will require a heavy lift launch vehicle. Ares 1 is developing many of the components needed for the heavy lift vehicle such as 5 segment solids, and the J–2X engines. Please comment on the role Ares 1 plays as a risk reduction program for the ultimate heavy lift launcher?

A2. Although the President's FY 2011 budget request does not include the Ares vehicles, the budget request includes three new robust research and development programs that will enable a renewed and reinvigorated effort for future crewed missions beyond LEO. One of the three programs is a Heavy Lift and Propulsion Technology Program, for which $559M is requested in FY 2011 and a total of $3.1B, is requested over five years. This aggressive R&D program will focus on the development of new engines and propellants, advanced engine materials and combustion processes that would increase our heavy-lift and other space propulsion capabilities and significantly lower operations costs, with the clear goal of taking us farther and faster into space.

The specific risk reduction achieved by the Ares I work will depend on the architecture chosen for a new heavy lift vehicle. However, the lessons learned from Ares I will serve to inform those decisions. With regard to the current program of record, NASA's Constellation architecture was designed to have two lift vehicles—the Ares I Crew Launch Vehicle and the Ares V Cargo Launch Vehicle (heavy-lift vehicle). The Ares I launch vehicle enabled early design and test of critical elements and subsystems that would be required by the later Ares V heavy-lift vehicle. Such common elements include the J–2X Upper Stage engine, solid rocket motor, avionics and software and other systems.

The Ares I vehicle took Ares V needs into consideration during development of the J–2X engine. The J–2X was planned to function as the Ares V Earth Departure Stage engine with only minor modifications to the Ares I engine. These modifications would be implemented via engine modification kits. Likewise, reductions were made to the Ares I/V solid rocket motor risks such as motor and nozzle design, materials selection and testing, recovery system (parachutes) testing and operations, and motor manufacturing.

Lastly, designing the Ares I allowed NASA to make an important technology leap in the design process. By transitioning from a 2-D, paper-based vehicle design and verification process to a 3-D model-based design environment, NASA was able to gain valuable experience with a new design system that can reduce costs while also increasing system reliability.

The Program is working to capture all of the knowledge learned from development efforts, including test flights. The Program has spent significant time recently focusing on its Preliminary Design Review (PDR) elements of which concluded in March. NASA believes that completing the Constellation PDR will support not only the close-out process for Constellation, but also will ensure that historical data from Constellation work is documented, preserved and made accessible to future designers of other next-generation U.S. human spaceflight systems.

Questions submitted by Representative Dana Rohrabacher

Q1. In the Launch Services Program NASA has generally required that a launcher demonstrate multiple successful flights before being considered for use launching science payloads and satellites. In some cases, up to 14 successful flights of the rocket were required before being used to launch a "Class A" satellite. By contrast, the Constellation Program is currently planning (subject to review) only one full-up test flight before placing astronauts aboard the Orion/Ares I. I understand that these two parts of NASA—manned and unmanned—have different requirements and operate with different rules, but in both cases the overall mission success is a primary objective. Can you please explain how these two systems of evaluating launch vehicles have evolved so differently, what are the similarities, and in the above example how NASA's Constellation program can comfortably accept a plan that demands 92 percent fewer test flights than what was required for a satellite program?

A1. The most important factor in determining when it is appropriate to fly crewmembers on a new test vehicle is the level of confidence the team has in safely conducting the test. In the case where NASA validates the technical requirements, designs and manufactures the flight and ground systems, writes the launch commit criteria and flight rules, performs all number of ground tests and engineering analyses, and conducts the reliability, safety and risk analyses, it has arguably maximized its understanding of and associated confidence in the system. Based on this, the team decides when to conduct its first crewed flight test. As the distance between NASA and the design, development, manufacturing, and operations increases, so does the Agency's reliance on demonstrated reliability, and/or other government certifications (i.e. Russia's ROSCOSMOS or the U.S.'s Federal Aviation Administration). NASA has not come to a final determination on the number of test flights that would be required prior to sending NASA astronauts into space using the crew launch vehicle under the Program of Record.

Regarding the comparison with the LSP, NASA has a range of options available depending on the launch system's proven reliability, the value of the payload, and the certification status of the provider. In some cases, this program has little insight into, or oversight of, the commercial launch providers. In those cases, NASA requires a demonstration of 14 successful launches for certification of the launch vehicle for high value payloads. This certification option, which is rarely chosen, is predicated on an assumption of no prior knowledge about launch vehicle performance, and limited government oversight into the design and operation. Another option is to fly the NASA payload on a relatively new system with as few as three flights (two successes in a row), but with substantial NASA process requirements and insight into the contractor's design, engineering and operations processes. For lower value payloads with a higher risk tolerance, another certification category is available. It only requires one successful flight of the launch vehicle and a significant technical assessment.

NASA's ongoing human spaceflight program has established a host of safety and mission assurance activities including (subsystem) tests, verifications, and analyses, which would establish a level of confidence in the vehicle's performance prior to the full-system test launches. Decisions regarding the needed number of full-system test launches should account for these assurance activities.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Mr. John C. Marshall, Council Member, Aerospace Safety Advisory Panel, National Aeronautics and Space Administration

Questions submitted by Chairwoman Gabrielle Giffords

Q1. As you know, the Augustine Committee projected that commercial crew transportation could be available by 2016. It does not appear that this projection reflected the time needed for all of the milestones that must be met prior to the point at which NASA would be able to use such services to fly its astronauts to the ISS such as the time needed to get Congressional authorization and appropriation of funds; agreement on human-rating and other safety standards and means for verifying compliance; development of a regime for certification; and contract competition, negotiation and award of contract (S), and potential protest(s) by losing bidders. These are no small tasks, and it is not obvious that any of them could be skipped if the government is to make use of those services.

a. In your opinion, what are currently the largest technical challenges or hurdles that potential commercial crew transportation providers are facing that might cause delays to their projected initial operating dates?

A1, 1a. The milestones that you mention are all important. The process for enabling the current commercial cargo providers to provide crew transportation has not yet been initiated to any significant extent. Although there has been considerable discussion about this topic by some manufacturers' leaders, and most recently by the Augustine Committee, the "COTS–D" portion in the current agreements still remains a potential add on to the commercial cargo delivery demonstration projects. Thus, the "projected initial operating dates" that might be achieved with the current designs are unclear. This said, the two NASA contractors currently in the program have stated that their designs could be adapted to human transport. However, they have made these statements without having the detailed requirements for the necessary safety certifications. This is because NASA has neither developed those requirements nor provided them to the contractors.

Clearly, the single most important technical challenge to commercial crew transportation that remains is developing the standards by which the suitability for human transport will be judged. Likewise, the process and authority for validating that those standards have been met—initially in the capability of the design and then through the construction and maintenance of the vehicle for its entire life cycle—also must be developed. Without firm performance criteria and the definition of the certification process for these criteria, the contractors' abilities to meet any initial operating dates for the current designs remains speculative.

Key hurdles to achieving certifiable crew transportation capability include:

1. Clear technical criteria for the vehicle's design performance and capability must be established and provided to all entities wishing to vie for providing the service.
2. The process for overseeing the design's development and validation must be created.
3. The technical details for the necessary data submissions, design reviews, analysis, testing, and validation of results must be established and instituted via contract with the manufacturers.
4. The process and authority for overseeing that the necessary safety is maintained through proper maintenance and support throughout the vehicle's life cycle must be developed, approved, and instituted.

b. How confident can the Congress be that a commercial crew capability can be operational in 2016 while still having to carry out all of the activities that need to be completed before the first NASA astronaut can safely ride on an operational vehicle to the International Space Station?

A1, 1b. NASA recently has begun to develop definitive standards for assessing design capability for crew transport. The criteria for safely docking vehicles with the ISS is already published and has been provided to the current commercial cargo contractors; however, it must be clear that this is only for protection of the ISS and does not provide any safety considerations for either humans or cargo inside the vehicle. If things move steadily and the Agency receives funding to contract for necessary activities, six years seems an adequate period to accomplish this objective. However, any effort to assess the feasibility of the 2016 operational start date for current designs would be premature since assessments of the current design developments against the criteria have not taken place. This is principally because the criteria necessary for that assessment are not yet fully determined. As a reference point, it took 10 years from program initiation to first flight for the space shuttle, and 10 years to reach the Moon with Apollo. Therefore six years duration, since we are building on the foundation of the existing cargo programs, seems like a reasonable time period.

However, there are many variables that can have a profound effect on the duration, three of which are particularly noteworthy. First, these vehicles and their launch systems have to demonstrate that they are capable of reaching LEO and safely delivering cargo to ISS. Obviously, success in this endeavor would be a large risk mitigator for extending the use of these vehicles to human transport. Second, the current designs have to be assessed against the previously described criteria, which will in no doubt drive needed design changes or additions. These modifications must be within the vehicle's design concept, i.e., technically feasible to incorporate into the design without causing the approach to be altered fundamentally. Third, these changes will have to be described in contractual documents and placed in an RFP. That RFP will result in a priced proposal that must be negotiated and funded. It has to be presumed that the funding needed to incorporate these changes/modifications/certifications will be provided.

Q2. You make it clear in your prepared statement that the ASAP Panel recommends that NASA be "hands-on" in its approach. Why do you think NASA needs to be "hands-on" in its involvement?

A2. Without direct involvement in planning, design, testing, and validating the design, NASA cannot state with assurance that the necessary safety level has been achieved. NASA must stay engaged in the entire process to ensure the level of safety is achieved.

Q3. "In your written testimony, you state that it is the ASAP position that "NASA is best qualified to be the oversight body for each of these actions (demonstration, verification, and certification prior to NASA's use for crew transport) *as today only NASA has the competence in hand to effectively audit the complex technical work required." Can you elaborate on why the ASAP believes that?"*

A3. While NASA currently has no explicit safety requirements for crewed COTS systems and will have to tailor the existing processes significantly, it is the only agency in the US Government that has a knowledge base for the complex tasks necessary to determine whether a given space vehicle is safe enough to carry US astronauts. This knowledge base includes the myriad technical standards that hard won experience has shown to be essential to ensure inherent safety for the hardware. It also includes the test and evaluation capabilities and human rating process capabilities (noted previously) that validate proposed designs as safe for these astronauts. Please note that mission safety approval for NASA crew member transport to LEO, ISS docking and return is not the same as safety approval for private launches, for which the FAA is, and should remain, responsible.

Q4. In the ASAP's 2008 Annual Report, the panel notes that "NASA has an important one-time opportunity to better interweave safety as a consistent and more powerful operating parameter by hardwiring safety into the fabric and procedures of the new flagship exploration program, Constellation."

How would NASA infuse a similar strong safety culture into the agency if NASA were to purchase crew services from a commercial provider in lieu of developing the Constellation launch system?

A4. In our 2008 Annual Report regarding Constellation safety opportunities, the ASAP wrote: NASA should institutionalize safety programs, systems, processes, and reporting procedures including:

- Robust, well-publicized safety programs that mirror industry best practices, including using current world-class systems and incentives as models
- A safety management system that tracks accidents, mishaps, close calls, audit results, lessons learned, and data trends for these and other leading indicators
- Consistent methodologies to identify hazards and to manage, articulate, and reduce risks
- Defined, timely process for investigating, analyzing, and reporting on accidents
- More rapid and thorough determination of root causes
- Standardized accident report format, timeline, database, and metrics

- Timely, possibly Web-based distribution of lessons learned to prevent mishap recurrences

Most of this still applies with little or no modification. However, the structure NASA will use to gain the insight and / or oversight to implement a safety program for commercial providers remains to be determined. Certainly, the U.S. Department of Defense (DoD) and the aerospace industry have learned how to work together to benefit safety when DoD engages in contracts with private industry for both weapon systems and critical services. Perhaps the DoD approach offers a good model.

In the ASAP's opinion, a sufficient safety program cannot be established in a "hands-off" contractual relationship.

Questions submitted by Representative Pete Olson

Q1. Since a significant portion of launch failures are due to human error it is critical to have a strong safety culture. The Columbia Accident Investigation Board reiterated again the importance of a strong safety culture. Would a shift to commercially provided low-Earth orbit launch vehicles disrupt that culture at NASA? Could that be cause for concern?

A1. The ASAP believes that a good safety culture is advisable for any organization, regardless of its work, and ideally is present due to ethical leadership, good systems, and the correct "tone at the top." The ASAP continues to assess NASA's safety culture, and while progress has been made since the CAIB report, our reports contain additional recommendations relative to safety culture. It is difficult and rare for an organization to achieve a "perfect" safety culture, and it is even more difficult to maintain one over time.

In this regard, NASA will need to ensure that any organization that may provide a crewed vehicle in the future actually will value a strong safety culture. Role modeling and ensuring a strong safety culture among NASA's contractors and potential partners will remain a difficult, yet doable, leadership task. Establishing a good safety culture in one's own organization is hard work. Fostering it within another organization, where one does not have complete control, is even more difficult. NASA has experience working with many contractors and has been vigilant in establishing good safety partnerships with them. It is the Panel's expectation that the current emphasis on contractor safety would continue if firms were contracted for Low Earth Orbit (LEO) launches, and that NASA would continue to work to improve its own safety culture and the safety culture of those firms.

Questions submitted by Representative Dana Rohrabacher

Q1. What does the Aerospace Safety Advisory Panel believe are the most important steps to enable NASA to seriously consider, evaluate, and possibly implement a commercial crew competition?

A1. On numerous occasions, the ASAP has addressed the urgent need for establishing the human rating requirements, airworthiness criteria, and certification requirements for a possible commercially developed vehicle that may be used to transport NASA crew. It is essential that these requirements be considered and, as appropriate, incorporated into the on-going design phase as early as possible. However, the scope of this question extends beyond the preparedness activities that are needed to ensure that an acceptable level of safety is achieved. To a large extent, it is equally important to ensure that the program's budgeting and planning process is initiated quickly. With this in mind, the ASAP notes the following serious challenges that will need to be met to successfully implement a commercial crew competition and offers the following observations:

A. NASA has not yet committed to developing a commercial crew transportation capability. If NASA elects to proceed in that direction, a strong message needs to be communicated publicly that commercial crew transportation is a priority NASA mission and the mission's requirements and objectives must be clearly stated. NASA should take steps to ensure that the impending Administration's decision for Exploration (based on the review of the Augustine's human spaceflight study) re-affirms the need for NASA to assist in developing a commercial crew transport capability.

B. It is not yet known which organization within NASA would assume responsibility for developing and implementing this program. Therefore, NASA will need to identify the Program Manager and provide adequate resources to address the performance, technical, schedule, and cost requirements and analyses in formulating the overall program plan.

C. NASA has not developed a program, acquisition strategy, budget, or initiated the legislative process necessary to obtain authorization for a COTS–D vehicle. Currently, NASA only has an option to exercise a COTS–D (crew transport) program under the Commercial Cargo and Crew Transportation Program. Space X currently has an unfunded Space Act Agreement option to demonstrate a COTS–D program. While NASA may also conduct a new competition for one or more crew demonstration partners, plans for implementing these options cannot go forward without authorized funding.

D. NASA needs to determine to what extent and how it will be involved in the commercial providers' processes and activities for defining the appropriate oversight and insight to ensure astronaut safety so that potential commercial partners can be informed.

E. NASA needs to determine to what extent it may provide enabling technologies and capabilities, including actual hardware or designs (such as that for the Orion), so that potential commercial partners can be informed.

Q2. During the Q&A period, you mentioned that the ASAP had visited with Orbital Sciences regarding their COTS development program, and stated that they did not see any existing commercial market for cargo (and potentially crew) delivery to ISS. Did you ask the same questions(s) of SpaceX, and what was their response?

A2. The original question by Chairwoman Giffords was ". . . do our witnesses believe that would-be commercial crew transport service providers be able to garner sufficient revenues from non-NASA passenger transport services to remain viable over this time period as well?" My response to this question where I noted that we asked Orbital Science if they had done a market analysis to find other revenue sources was directly to the issue of crew transport services, not commercial cargo markets. This said, SpaceX management was not asked this question. Neither did they indicate whether alternative markets have been identified for their vehicle.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Mr. Bretton Alexander, President, Commercial Spaceflight Federation

Questions submitted by Chairwoman Gabrielle Giffords

Q1. What is the industry's understanding of NASA's human-rating and safety requirements, both technical and operational? Is there an expectation by the industry that finalized requirements will be developed in conjunction with NASA?

A1. The Aerospace Safety Advisory Panel correctly points out that NASA has not yet developed standards and processes for human-rating commercial vehicles. Until such time as commercial human-rating standards are determined, industry continues to develop vehicle hardware based on the only standards available: those NASA established for its own vehicles, known as NPR (NASA Procedural Requirement) 8705.2B, effective May 06, 2008.

Early dialogue between NASA and the commercial spaceflight sector on the nature of human-rating requirements for commercial systems is crucial, with demonstrated reliability, robust test flights, and a reliable crew escape system being key. To work with NASA and the FAA, US. industry has established a Commercial Orbital Human Spaceflight Safety Working Group, under the leadership of the Commercial Spaceflight Federation. The goal of the effort is to develop industry consensus on principles for safety of commercial orbital human spaceflight. Consensus has been reached among a number of companies on fundamental principles that will form the basis for our engagement with the FAA and NASA, but much more work remains to be done.

Q2. During the hearing, Mr. Marshall said that some entities might not agree to a "hands-on" NASA role. Have federation members discussed what activities and level of scrutiny by a federal entity would amount to a "hands-on" relationship with which they could not agree? Can you provide examples of the types of activities and level of scrutiny that would create an unacceptable "hands-on" relationship? What level of NASA involvement would be acceptable?

A2. The commercial spaceflight industry believes strongly in the importance of a close relationship with NASA. The level of oversight and insight shared between NASA and FAA is a critical topic that is being addressed by, among other bodies, the Commercial Orbital Human Spaceflight Safety Working Group. Since NASA, FAA, and commercial spaceflight providers are just beginning their dialogue, it is not yet possible to state whether any specific requirement will be a subject of dialogue or discussion between the stakeholders.

As NASA Administrator Charles Bolden stated February 1: "Now, as 50 years ago when we upgraded existing rockets for the Gemini program, NASA will set standards and processes to ensure that these commercially built and operated crew vehicles are safe. No one cares about safety more than I. I flew on the space shuttle four times. I lost friends in the two space shuttle tragedies. So I give you my word these vehicles will be safe." The commercial spaceflight industry will work closely with Administrator Bolden and others to make sure that this objective is realized.

Q3. Your prepared statement does not directly address how experience in reentry and landing will be obtained by potential commercial providers. By what means and in what timeframe will the commercial space transportation industry secure such experience?

A3. Reentry and landing is a critical portion of human spaceflight that is essential to safety. It is our expectation that commercial providers will not place astronauts on an untested capsule, but rather these systems will have gained flight experience with reentry and landing before commencing manned flights with NASA astronauts aboard. In addition to full orbital flight tests, commercial providers may also conduct suborbital tests, either as part of a subscale test launch or as a test of the launch abort system, which will therefore provide additional experience with the reentry and landing phases of the mission profile. As no provider agreements for a full Commercial Crew program have yet been signed, the exact timeframe is yet to be determined on a per-company basis. Further, US. aerospace companies have been a part of every US. human spaceflight since the program began and have substantial technical expertise in reentry and landing systems and environments.

Q4. In your prepared statement, you state that in addition to FAA's existing regulatory authority as codified in U.S. law, industry will satisfy customer-specific requirements levied by NASA in partnership with industry. With regards to your *reference to existing FAA authority, are you proposing that NASA astronauts fly under "informed consent", which is the existing regulatory framework?*

A4. The Federal Aviation Authority's Office of Commercial Space Transportation currently levies different requirements for different categories of individuals, which include "crew" and "space flight participants." The exact nature of the regulatory framework that would apply to NASA astronauts will require dialogue between NASA, the FAA, and the commercial space industry. Through the Commercial Orbital Human Spaceflight Safety Working Group, industry stands ready to engage in this dialogue and determine the best path forward. However, it is vitally important for the viability of future commercial human spaceflight providers that launches be conducted under the same legal and regulatory framework, regardless of whether the customer is the U.S. government or a private entity.

Questions submitted by Representative Marcia L. Fudge

Q1. The discussion of safety requirements for crew and passengers on commercial transportation systems has, up to now, primarily focused on suborbital flights. Has the commercial space transportation industry identified any additional safety-related R&D requirements to enable future orbital flights by commercial crewed transportation systems?

A1. As compared to suborbital flights, orbital flights have more demanding engineering requirements in specific areas, such as: higher heat loads on re-entry, more powerful and longer engine firings, additional risk due to micrometeroid impact, more involved communications downlink to Earth, additional attitude control requirements, more complex abort scenarios, etc. Since the commercial crew program could be seen as commercializing accomplishments similar to those of the 1960s Gemini program, none of these problems require new technology to solve, but they would all benefit from additional R&D to improve capability, reduce risk, and reduce costs.

Q2. Are there any R&D efforts currently underway at NASA's Glenn Research Center that would have applicability to potential commercial human space transportation systems? Does the commercial space transportation industry have suggestions on how NASA's Center R&D programs could contribute to enhancing the safety of potential commercial human space transportation systems?

A2. Yes, there are multiple R&D efforts currently underway at Glenn Research Center that would be useful for commercial human space transportation providers. Facilities such as the Plum Brook Station (PBS), which has significant capability for full-scale upper-stage engine testing under simulated high-altitude conditions, would be useful to commercial providers. Plum Brook has the Space Power Facility as well as a hypersonic wind tunnel and cryogenic test facilities. Research in the fields of combustion, reacting flow systems, fluids, and materials testing of structures for atmospheric and vacuum/space environments are some of the areas of interest to the industry. Other R&D efforts underway at Glenn's Zero Gravity Drop Tower and the Spacecraft Propulsion Research Facility will also help enable future innovation for commercial space launch providers. Some ways in which NASA's Center R&D programs could contribute to commercial spaceflight safety is through easier access to government test facilities, as well as enhanced interchange of technical information from NASA.

Q3. If NASA were to use commercial transportation systems to fly its astronauts to the International Space Station, would the commercial space transportation industry envision these astronauts being passengers or crew members? What sort of training would the industry envision as needed for these astronaut passengers? If spacecraft are piloted by provider crew members, how would their training differ from that received by NASA's astronaut passengers?

A3. The exact regulatory framework that would apply to NASA astronauts will require dialogue between NASA, the FAA, and the commercial space industry. Through the Commercial Orbital Human Spaceflight Safety Working Group, industry stands ready to engage in this dialogue and determine the best path forward for the FAA, NASA, and commercial industry.

Questions submitted by Representative Pete Olson

Q1. In preparation for commercial attempts to deliver cargo to the International Space Station, the COTS providers have been working closely with NASA to *evaluate whether they can comply with NASA's Visiting Vehicle requirements that govern proximity operations around the ISS. Is there anything preventing NASA from working with potential commercial providers, whether COTS companies or United Launch Alliance, to establish the safety requirements processes and identify the modifications that would be required for those vehicles to meet NASA's human-rating requirements?*

A1. We do not believe at this time that there are any obstacles to cooperation between NASA and commercial companies in the development of safety requirements processes and identification of needed modifications to vehicles. The Aerospace Safety Advisory Panel recently stated that NASA should "accelerate the level of effort underway" to develop these commercial requirements. The commercial spaceflight industry is ready to work with NASA on these critical issues, and in fact has already begun engaging with NASA through the Commercial Orbital Human Spaceflight Safety Working Group. While the Commercial Spaceflight Federation has taken the lead in organizing the effort, the working group includes representatives from a broader spectrum of companies, including several of the major aerospace primes and more traditional government space contractors. The goal of the effort is to develop industry consensus on principles for safety of commercial orbital human spaceflight. So far, we have met among industry and have begun to engage NASA and the FAA.

Q2. Recently there seems to be a great deal of interest among the potential commercial space providers to enlist the government as the primary buyer of space systems. Presumably, this is because the government is currently the only known market for these services, although the industry is hopeful that non-governmental buyers will emerge. If no outside commercial market materializes, as was the case with early claims that a backlog of commercial satellites would help to reduce the cost of the development and operations of EELVs, wouldn't the governments' costs ultimately be higher since it would eventually have to pay for all the development and operational costs?

A2. The Augustine Committee stated the following findings in its final report:

"During its fact-finding process, the Committee received proprietary information from five different companies interested in the provision of commercial crew transportation services to low-Earth orbit. These included large and small companies, some of which have previously developed crew systems for NASA. The Committee also received input from prospective customers stating that there is a market for commercial crew transportation to low-Earth orbit for non-NASA purposes if the price is low enough and safety robust enough, and from prospective providers stating that it is technically possible to provide a commercially viable price on a marginal cost basis, given a developed system.

None of the input suggested that at the price obtainable for a capsule-plus expendable-launch vehicle system, the market was sufficient to provide a return on the investment of the initial capsule development. In other words, if a capsule is developed that meets commercial needs, there will be customers to share operating costs with NASA, but unless NASA creates significant incentives for the development of the capsule, the service is unlikely to be developed on a purely commercial basis."

That is, the Augustine Committee found that non-NASA customers for commercial crew services did exist, but not in sufficient quantity for the business cases of private companies to close if they had to fund the development entirely on their own. On the other hand, if private industry and NASA share the development costs, then all parties will benefit. In particular, one additional market has been proven on a small scale, which is private citizens paying to travel to space. Over $150 million has been already paid by seven private citizens to travel on a Russia Soyuz to the International Space Station, at a steady rate of about one mission a year. In fact, the demand for this service has continued to increase despite an almost doubling of price from under $20 million per seat to now over $35 million per seat. Furthermore, when Commercial Crew taxi services begin in the United States, demand will rise because would-be travelers, who are often business leaders running companies, will no longer have to spend six months training in Russia with limited contact with the outside world. Since American services will not require overseas training of that duration, will not require learning the Russian language, and will likely undercut the Russians in per-seat cost, the market is likely to increase for private space travelers.

Other, not yet proven, markets for additional flights of the capsules include: (a) sovereign clients, in which other countries purchase seats on American vehicles rather than the Russian Soyuz, and (b) industrial clients: since as Commercial Crew reduces the cost and increases the frequency of access to space, there could be increased interest in on-orbit industrial applications.

When considering the potential of other markets, it is important to note that all Commercial Crew providers will use launch vehicles that already exist, such as the Atlas V, or in the late stages of development, such as the Taurus II and Falcon 9, and all of these vehicles will launch satellites and cargo before putting astronauts on board. Accordingly, it is already the case that a proven commercial market exists for at least the launch vehicle portion of each rocket-and-capsule system. Spreading the costs of a commercial system between the cargo, satellite, and crew markets will reduce the burden for each customer (NASA, DoD, and commercial customers).

Q3. Given that the emerging commercial providers appear to believe strongly in an evolutionary approach to design and safety innovation to be achieved through flight experience gained from revenue flights undertaken without any prior safety certification regime, wouldn't premature reliance on the government as the dominate or only customer inhibit the ability of the emerging commercial providers to sustain the innovation they believe is essential to their long-term commercial success?

A3. As the Augustine Committee stated the following findings in its final report: "unless NASA creates significant incentives for the development of the capsule, the service is unlikely to be developed on a purely commercial basis." With NASA as a significant early customer, commercial industry will still be able to more rapidly incorporate innovations and technology upgrades than under a government program designed to for a 20-to-30 year operating lifetime.

Q4. What do potential commercial crew transportation services providers consider to be an acceptable safety standard to conform to if their space transportation systems were to be chosen by NASA to carry its astronauts to low Earth orbit and the ISS? Would the same safety standard be used for non-NASA commercial human transportation missions?

A4. Safety is paramount for the commercial spaceflight providers. Indeed, commercial vehicles such as Atlas V and Delta IV, developed with substantial private funding and engineering expertise, are already trusted to launch key government national security assets upon which the lives of our troops overseas depend. Since probabilistic risk assessment calculations account for part failure, and do not account for most of the root causes of accidents historically, such as human error or design flaws, and since even reliable vehicles have historically suffered a period of "infant mortality," the commercial spaceflight industry believes that they will in fact achieve higher safety than that of government systems that intend to put human beings aboard on early orbital flights of the system. Commercial industry believes safety must include the following:

- Demonstrated reliability through multiple orbital unmanned flights of the full system
- Not placing crews on initial flights, since early flights are historically most risky
- A highly reliable crew escape system
- Standards-driven design and operations

Industry believes that the safety of commercial spaceflight must be significantly greater than that of the space shuttle in order to be successful. In addition to the FAA's existing regulatory authority, as codified in U.S. law, industry will satisfy customer-specific requirements levied by NASA in partnership with industry. This process has already begun with the cooperation of the stakeholders involved. NASA and FAA will be there every step of the way, and will have oversight during design, testing, manufacturing, and operations.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Joseph Fragola, Vice President, Valador, Inc.

Questions submitted by Chairwoman Gabrielle Giffords

Q1. The Augustine Committee's report cited five basic questions that could for the basis of a plan for the U.S. space flight program, but "how could crew safety be dramatically improved" was not one of them. Should it have been? And if so how would it have informed their deliberations?

A1. It is my opinion that the question of how could crew safety be dramatically improved should have not only been one of the five basic questions for the basis of a plan of the U. S. space flight program, but that it should have been the primary question. In fact it is difficult for me to understand how a committee could, on the one hand state that crew safety was the *sine qua non* of their work, and yet not include crew safety as a primary question. I believe if they had included it as a primary question they would have understood better how deliberately during ESAS, and subsequent to ESAS in the development of the Ares I vehicle design the thrust of all decision making was toward the development of a dramatically safer crew launcher than heritage systems such as the Space Shuttle or commercially available systems, such as Atlas or Delta.

Q2. Reliability and safety seem to be used interchangeably by some when discussing crew safety. Are they really the same thing, and if not what is the distinction? How important a distinction is it?

A2. There is a lot of confusion in the meaning of the term safety. The definition varies and to some, particularly those in the systems safety community, safety includes any significant loss. Those in the risk assessment community include only losses of life. However neither community would accept the fact that the terms reliability and safety are interchangeable when it comes to loss of life. The important issue to recall as it relates to launch vehicles is that reliability is indistinguishable from safety for unmanned spacecraft payloads, but the two are crucially different for manned space vehicles. This is because of the important distinction between relatively benign vs. catastrophic failure modes, and because of the existence of an abort system.

These distinctions mandate that safety consider the additional probability of the crew surviving conditioned on a mission failure. This latter conditional probability depends on the severity of the initiating mission loss accident and the robustness of the abort system. A good example would be Apollo 13. The mission failed in such a severe way that not only was the Command and Service Module disabled, but all the services in the service module were destroyed. This implied that the abort system, the Lunar Module, had to be robust enough not only to perform the electric power functions of the CSM, but also to provide all the other life sustaining functions until the Command Module could be employed for re-entry. A less severe accident, say a benign engine failure of the Service Module engine, would have not required the additional risk of conversion of the CO_2 extraction system for example. The point is that the abort system must be robust enough to address the full spectrum of post accident conditions and allow the crew to survive them. So the conditional probability of an effective abort given a LOM event is an important distinction between reliability and safety.

Q3. How does one calculate meaningful safety characteristics such as loss of crew for vehicles that have not yet entered the hardware phase?

A3. Crew safety can never be guaranteed even with a vehicle that has been built and has had a significant record of mission success. However this does not mean that designs that include certain features are not more likely to produce a safer design than those that are not. In particular in my testimony I provided four rules that I believe would enhance the safety of a new launcher:

1. Make it as inherently safe as possible. That is, make it reliable AND select a design with benign failure modes.
2. Separate the crew from the likely source of failure. That is, put them on top of the stack where "God meant them to be".
3. Establish credible abort triggers balancing warning time with the threat of false positives.
4. Include an abort system tested and verified for robustness for safe escape and recovery.

To calculate meaningful safety characteristics for vehicles that have not entered the hardware phase one uses historical operational data from heritage systems to establish a "surrogate" model of the new design to estimate the inherent safety, that is mission reliability, and the spectrum and post incident environments likely for credible mission loss events. A surrogate is constructed for a new launcher much in the same way that an opening price is established for a new initial product offering in the marketplace. That is, in the case of an IPO the analyst looks at comparables that are in the market, their product lines, and their associated market prices, and constructs a "shadow price", by reflecting the product line of comparables onto the product line of the IPO and adjusting for competitive distinctions. This shadow price becomes the opening market price. In the case of a safety surrogate, the analyst reviews all type comparables, in this case launchers, their historical heritage launch reliabilities and risk driving features, and constructs a "shadow risk" reflecting these features and associated risks onto the features in the new launcher adjusting for differences that make a difference in the risk driving elements of the new launcher design.

Once the surrogate is established each of the credible incident environments are simulated to determine the physical impact of the radiative, impulse pressure wave, and fragmentation environments on the crew safe abort given the stack geometry, launch abort system design and crew module fragilities, throughout the ascent trajectory. The combination of the geometry, post accident insult environment and the fragilities of the crew module forecast the overall abort effectiveness of the configuration given the inherent reliability of the launcher once deployed.

This approach is distinguished from the more traditional launch reliability approach used in the past by its reliance on historical data, the establishment of a vehicle surrogate from the top down, that is on a functional not component basis, so as to capture the primary causes of historical failures, and the use of first principles physics codes to establish the post accident environments and the corresponding abort effectiveness.

It is believed that employing such an approach provides estimates of loss of crew probabilities, within reasonable uncertainty bounds, so as to allow for discrimination of the crew safety potential among proposed designs.

Q4. What are the key determinants in designing an effective abort and escape system? What compromises should be avoided?

A4. The most important determinants in designing an abort system are the balancing of escape acceleration and acceptable g load on the crew so as to provide for maximum separation distance from the approaching hazards without endangering the crew further during the abort and the avoidance of false positives that would cause aborts from an acceptable system. What should be avoided is to use the abort system as a crutch against unacceptable inherent safety for example, by claiming indefensibly high levels of abort effectiveness.

Q5. What safety considerations should guide the Congress' evaluation of the implications of NASA relying solely on commercially provided crew transport and ISS crew rescue services?

A5. As was mentioned, even a significant record of mission success is not enough to ensure safety at dramatically higher levels than those currently provided by the shuttle. Congress should require that NASA become involved in a wholesale evaluation of the design features of each proposed design including that of the crew module. and the launch abort system. This evaluation should include the heritage of those features in terms of their historic performance especially as it relates to the post incident conditions that would be imposed on the crew. Congress should require that NASA impose strict first principles physics based simulations to establish a credible estimate of the abort effectiveness to be applied to the integrated crew launch stack, including the launcher, the launch abort system, and the crew module. Congress should also require that NASA establish resident inspectors at the production facilities of all the major manufacturers of the launch, crew module, and launch abort system. It also should require process control and inspection during manufacturing and testing, and the identification and close out of anomalies including design and or process changes implemented and their effectiveness. Finally Congress should require that NASA impose a strict and challenging ground and flight test program for the proposed launch abort system, including a full up flight test of the system to ensure its robustness.

Q6. The Augustine Committee's report mentioned that a leading objective of the ESAS effort was to minimize the gap between the last shuttle flight and that *of the new vehicle. You were a member of the study. Were there any other major objectives?*

A6. Yes there were. The most important major objective, and the one that I was most intimately involved in, was to ensure that the CAIB recommendation that the replacement crew launcher for the shuttle would be an order of magnitude safer than the shuttle. Other major objectives were to fit into the funding profile, to allow for payload performance objectives to be met, and to ensure that the architecture chosen was capable of enabling a path forward to a crewed lunar and eventually a crewed Mars mission.

Q7. How meaningful are the distinctions between the Loss of Crew figures for different options contained in the Exploration Systems Architecture Study (ESAS)?

A7. The ESAS, as its name implies, was directed at the selection of an architecture to enable exploration beyond low earth orbit. The focus was therefore on discriminating among the suggested alternative architectures, and associated elements, so that the most effective one would be selected to be carried forward. In this regard the Loss of Crew estimates made at the time of ESAS were directed at highlighting differences that made a difference among the alternatives. The estimates were not intended to represent the absolute Loss of Crew risk of any of the alternatives but rather to distinguish among them. In particular, estimates of the abort effectiveness of the various alternatives were based upon rough estimates of the post accident physics, and not on the more detailed first principles physics code results subsequently obtained for the Ares I vehicle as it has progressed through development.

Q8. Having been on the ESAS effort, you have a unique perspective on what would be needed to replicate similar analyses of alternatives your team did not consider. If NASA was to be directed to perform a similar safety analysis on another alternative, what is the rough estimate of the cost and time it would take to perform the physics based analysis that was done for the recommended launch alternatives—those that resulted in Ares I and Ares V.

A8. First I have to correct two impressions that seem to be included in the question that are not precisely correct. The ESAS team considered many of the alternatives that have been subsequently suggested including the shuttle side-mount, and the EELV alternatives of the Atlas V and Delta IV families, we just did not consider them in the detail that we subsequently did for the selected Ares I alternative. Also, we did not, at least at the last of my involvement, consider the detailed physics analysis that we had performed on Ares I on the Ares V vehicle because subsequent to ESAS we were not considering it as a potential crew launcher.

The performance of a similar analysis to another alternative would depend on how much of the work we have done so far could be used and how readily available finite element models of the alternative would be. The physics work would have to be done on a massively parallel computational system such as the Pleiades project at the NASA Advanced Supercomputing (NAS) Division at Ames. This Supercomputer is dedicated to the Exploration program so a cost is not available. We do know that it took 5 million hours of equivalent CPU time for the Ares I analysis. These estimates assume the availability of a basic understanding of the aerodynamics, trajectory information of any of the alternate vehicles, which are generated as a matter of course in the design process by the aero analysis teams at MSFC and ARC. That is, this information would have to be generated in order to perform a meaningful evaluation of abort effectiveness. NASA JSC has already completed some exploratory work on the side-mount. If this work not sufficient additional exploratory CFD would have to be performed whereas existing Orion abort trajectory/aerodynamic information for Ares I could be used to arrive at a first order approximation for other in-line concepts.

The calendar time estimated for the side-mount would be 6 months if extra work were required and 4 months for each of the other concepts. The labor costs would vary depending on the concept, but a rough estimate of the cost would be between $250–350K per concept. However the actual cost would have to be negotiated between NASA Ames and its chosen contractor and work could be done in parallel if multiple concepts are to be considered.

Q9. In your opinion, what would be required in practice to implement the Augustine Committee's suggestion that NASA exercise a strong oversight role in assuring commercial vehicle safety?

A9. To a degree this question has already been answered in the answer to question 5, but a summary of what would have to be done is mentioned here. Firstly NASA would have to appoint a team of people to sit down with the proposed commercial supplier and learn the launch vehicle from top to bottom. Then the team would have to develop an understanding of the relationship of the various systems and components implementing the various critical functions on the proposed launcher and that of the historical heritage of launchers. The NASA team would then have to develop a surrogate of the proposed launcher by relating its critical functional implementation and associated failure modes to the historical heritage data set. The former analysis would attempt to establish the mission reliability of the proposed launcher in a crew application. (Note: This would be different from the launcher mission reliability in a payload application due the integration impact of the crew module and support systems module and the launch abort systems and due to modifications of the launcher systems, such as the addition of red lines on the engines and abort triggers on the vehicle.) The latter would establish the post accident conditions that would need to be modeled using the first principles physics simulations to establish the abort effectiveness.

Then, if the launcher is seen to have met the minimum conditions for consideration as a crew launcher, NASA would have to establish an on site inspection team at the facility of the manufacturer of all the major elements of the design. The contractor would be required to involve NASA in all the major tests performed on the vehicle and the associate launch abort system and crew module and its support systems module, review all anomalies and work with the contractor to close them out by design or manufacturing process changes. In short NASA would have to perform the same investigation it has had to perform on the Russian Soyuz, plus the additional manufacturing and process inspection that it has been unable to conduct on Soyuz in order to ensure that the launcher has been developed as an equivalent to a NASA developed vehicle.

Questions submitted by Representative Pete Olson

Q1. Part of NASA's rationale for selecting a solid rocket motor for the first stage of the Ares 1 is that it is inherently a simpler design with few moving parts. But other U.S. systems using liquid propulsion have been highly reliable as well. Taking into account their entire lifecycle, can you comment on the overall safety records of solids vs. liquid rocket motors and whether this should be a factor in the overall architecture? If a proposed commercial crew system relies on liquid boosters, or a combination of liquid and solid, how does that affect the Loss of Crew calculations.

A1. There is no doubt that liquid propulsion systems, especially those that have been proposed prior to the Ares I, have been shown to be highly reliable. In fact the work performed prior to and during the ESAS study indicated that a single core liquid would be an equivalent approach with the Atlas V being slightly preferred to the Delta IV from a safety perspective. The problem was that the payload of these vehicles was so limited that it was considered unacceptable as a crew replacement for the shuttle for either the lunar or ISS mission. The only single core alternative that had the thrust. capable of carrying the required payload was the 2.5 million pound thrust shuttle solid, (now about 3.0 million pounds with the 5th segment added). To compete with this capability the heavy EELV alternatives versions had to be considered and it is the addition of the two strap-on liquid core boosters that made the alternatives significantly more risky than the single core solid. In addition to the simple multiplication of engines and propulsion systems, which have been shown historically to be launch vehicle risk drivers, there were the additional fuel load and the potential for thrust imbalance problems. In addition, for the Delta IV heavy, the only heavy currently in operation, has flame pit H2 burn-off problems at liftoff. All of these contribute to the post accident risk consequences. It is the combination of the increased mission risk of the triple core heavy lift launcher and the post accident abort environment that causes the EELV alternatives to be forecasted to have almost three times the launch risk of the Ares I as I mentioned in my testimony.

So if a single core liquid booster would be able to lift the required six passenger Orion to the ISS, especially if it were the Atlas V, it would be a competitor to the Ares I, but we would have to fly at least two, and possibly three Atlas Vs to meet the payload requirement. Even though the Atlas V might expose the crew to an individual launch risk equal to that of the Ares I, the cumulative risk of multiple launches would again be significantly higher than a single Ares I launch even without considering the benign failure impact of the dominant solid booster failure modes. Therefore if crew safety is to be a significant discriminator among alternatives then it should be a factor in the overall architecture, and if it is the *sine qua non* as the Augustine report indicates then it should be the most critical factor.

Strap-on boosters in general represent a more difficult environment for crew escape in event of a launch catastrophe because they increase the probability of involvement of greater amounts of fuel in the post accident environment. This is true for both liquid and solid tandem or barreled boosters. However since liquid engines can be monitored and shut-down and since a significant portion of a liquid booster risk is in benign shutdown the impact on Loss of Crew risk is not as severe as with solids. When solids are used as either strap-ons (either tandem or barreled) to the central core booster the predominant historical failure modes of the solid, case breach or soft-goods (as in the case of the Challenger accident) or nozzle burn through, interact with the liquid core if the hot gas jet impinges upon the core as in the case of Challenger and the Delta II and Titan 34D accidents. The probability of this occurring is higher with a barreled solid because of its closer proximity to other solids and the liquid core so the solid angle of impingement is greater. However with tandem boosters there is the additional problem of thrust imbalance. That is the imbalanced thrust from one side to the other of the stack can cause significant abnormal additional loads on the stack that can cause aerodynamic breakup even if the hot gas plume does not impinge on the central core. This is particularly a problem when the tandem solid boosters are large and represent a major portion of that boost thrust as is the case for the shuttle and the Titan 34D. In fact post flight analysis of the Challenger accident indicated that the thrust imbalance was such that aerodynamic breakup would have probably occurred without impingement.

This post-accident interaction effect was known well before ESAS and was documented as part of the previous OSP investigations contained in the Bullman Report that I am unable to attach because of ITAR restrictions, but which has been supplied to the Subcommittee staff. In fact the Bullman participants were so aware of this fact that they recommended that solids not be used in a configuration of any future crewed vehicle. Specifically they recommended:

R8.2–2 Unless the Program is able to generate new data that demonstrates that SRM explosions are "abortable," the program should not plan to use ELV configurations with strap-on SRMs for crewed flights of the spacecraft. In addition to the stack explosion issue, the inability to terminate SRM thrust and its affects on separation profile must be assessed. Refer to the report reliability discussion for a quantitative discussion.

Thus, in answer to the second part of the question, yes the post accident impact of strap-on boosters would be felt for all cases and this is one of the reasons why, independent of the increased risk of additional hardware, a single core booster, either solid or liquid, is to be preferred to any configuration that would use strap-ons. Now the degree to which the incorporation of strap on boosters impacts the Loss of Crew risk depends on the type of strap-on and the overall configuration. In general liquid strap-ons have less of an impact than solids, and configurations with the crew on top have less of an impact than side-mount configurations. This can be seen in the comparative analysis chart given in my testimony where the liquid strap on configurations are slightly less risky than the solids, and the in-line Ares V crewed configuration is less risky than the shuttle derived side-mount. This figure can be used to grossly estimate the relative risk of the various strap-on configurations and explains why any of them, solid or liquid, in line or side-mount, would be expected to be more risky than the single core solid Ares I configuration. However, to understand the specifics and absolute values of the relative risks of the various configurations would require detailed post accident physical simulations similar to those already performed on the Ares I configuration.

Questions submitted by Representative Dana Rohrabacher

Q1. During the Q&A period, you seem to be explaining that in order to get the performance necessary to loft a crew capsule on an Atlas-class vehicle would require an Atlas 431 (or equivalent) with three strap-on boosters. Would you please explain the design and safety considerations associated with crew escape using existing or modified EELVs?

A1. The safest configurations, whether solid or liquid, are single core vehicles. This is not only because of the simpler design but also because of the limited fuel load and the elimination of potential interaction impacts subsequent to mission failure all of which increase the hazard potential of the post failure environment that the abort system must negotiate.

So if a single core liquid booster would be able to lift the required six passenger payload to the ISS, especially if it were the Atlas V, it would be a competitor to the Ares I, but we would have to fly at least two, and possibly three Atlas Vs to meet the payload requirement. Even though the Atlas V might expose the crew to an individual launch risk equal to that of the Ares I, the cumulative risk of multiple launches would again be significantly higher than a single Ares I launch even without considering the benign failure impact of the dominant solid booster failure modes.

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Thus, in answer to the second part of the question independent of the increased risk of additional hardware, a single core booster, either solid or liquid, is to be preferred to any configuration that would use strap-ons because it presents a less hazardous post mission failure escape environment. Now the degree to which the incorporation of strap on boosters impacts the Loss of Crew risk depends on the type of strap-on and the overall configuration. In general liquid strap-ons have less of an impact than solids, and configurations with the crew on top have less of an impact than side-mount configurations. This can be seen in the comparative analysis chart given in my testimony where the liquid strap-on configurations are slightly less risky than the solids, and the in-line Ares V crewed configuration is less risky than the shuttle derived side-mount. This figure can be used to grossly estimate the relative risk of the various strap-on configurations and explains why any of them, solid or liquid, in line or side-mount, would be expected to be more risky than the single core solid Ares I configuration. However, to understand the specifics and absolute values of the relative risks of the various configurations would require detailed post accident physical simulations similar to those already performed on the Ares I configuration.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Lt. Gen. (Ret.) Thomas Stafford, United States Air Force

Questions submitted by Chairwoman Gabrielle Giffords

Q1. As you know, the Augustine Committee projected that commercial crew transportation could be available by 2016. It does not appear that this projection reflected the time needed for all of the milestones that must be met prior to the point at which NASA would be able to use such services to fly its astronauts to the ISS such as the time needed to get Congressional authorization and appropriation of funds; agreement on human-rating and other safety standards and means for verifying compliance; development of a regime for certification; and contract competition, negotiation and award of contract(s), and potential protest(s) by losing bidder(s). There are no small tasks, and it is not obvious that any of them could be skipped if the government is to make use of those services.

- *In your opinion, what are currently the largest technical challenges or hurdles that potential commercial crew transportation providers are facing that might cause delays to their projected initial operating dates?*
- *How confident can the Congress be that a commercial crew capability can be operational in 2016 while still having to carry out all of the activities that need to be completed before the first NASA astronaut can safely ride on an operational vehicle to the International Space Station.*

Q2. What was the extent of the testing and analyses performed on the Gemini spacecraft and Titan launch vehicle before NASA was comfortable with system's safety? How "simple" was it to build safety into Gemini.

Q3. I understand that training for off-nominal operations is an important facet of crew training. Astronauts are acquainted with how to identify these off-nominal operations and apply ways to respond to them. During your illustrious career in human space flight, how important was training for off-nominal operations to enhance safety? What level of training would need to be performed to fly NASA astronauts on commercial transportation systems?

Q4. Do you have any concerns regarding the option of canceling Ares I to go to the ISS and relying on a new set of would-be commercial providers? Is there a risk of being in a situation where those emerging enterprises are deemed "too important to fail" and we end up having to support them at whatever cost and time it takes?

A1, A2, A3, A4. Chairwoman Giffords—With respect to your first question, I agree that the projections from the Augustine Committee did not reflect the time needed for milestones and issues that must be met for a certified rocket and a certified spacecraft before NASA astronauts would be launched to the International Space Station. As described in my testimony a human-rate launch vehicle and spacecraft must start from the first time drawings are put together. All of the issues you outlined can add a considerable length of time to the process. I have great confidence that to "really certify human-rated spacecraft with a launch vehicle will not be ready any sooner by any proposed commercial vehicles than those by NASA." Ares I Orion would have flown in 2013, but funds were taken to fly the Space Shuttle and complete the ISS due to the OMB not allowing NASA to request the adequate funding. As I outlined in my testimony, I doubt that the President was aware of the gap that OMB was causing in the schedule by not allowing NASA to request adequate funding and would require our crews and international partner crews to pay to fly on Russian launch vehicles and spacecrafts. I agree that this is no small task and do not see any items skipped if the government uses a commercial provider.

My opinion is that there are large technical challenges for potential commercial crew provided rockets and spacecrafts to meet the NASA Office of Safety and Mission Assurance requirements to meet initial operational dates. In response to your second point, as I expressed, due to experience in the Gemini and Apollo, I flew on three different types of vehicles and four different types of spacecraft and I do not feel that Congress can be confident that a commercial crew vehicle will be operational in 2016 and carry out all of the activities to be completed before a NASA crew is launched.

With regard to your second question, NASA required 39 months of testing and analysis on the Titan II launch vehicle and similar time on the Gemini spacecraft prior to the first launch. The major Titan II components, tanks, and structures for the Gemini spacecraft were built at the Martin Denver plant then shipped to a separate controlled assembly line at Martin's Baltimore plant. Here modifications were made to the booster and a series of safety modifications, including the Emergency Detection System, were installed on the booster. Most people today do not realize that there was a completely separate assembly line for the Gemini Titan II launch vehicle. The first and second stage Aerojet engines powered the Titan and were built in Sacramento under the special quality conditions; then shipped with an escort to the Martin plant where they were installed on the vehicle. These escorts stayed with the engines all the way through to Launch Pad 19 until launch.

With regard to your third question, to the four prime missions that I flew and three back-up crew missions that I was a member of, we literally spent hundreds of hours in the factory for each mission. We also spent hundreds of hours in the spacecraft processing, testing, and checkout before launch. For simulations we worked hundreds of hours and ran all of the nominal and off nominal operations and all emergency situations. Many of the simulations were integrated with the Mission Control Center. The level of training needed to fly astronauts on commercial transport systems should be no less than our previous experience.

With regard to your fourth question, I do not have concerns that Ares I, which has been designed from every piece part up onward to meet the NASA Mission and Safety Assurance and human rated factors similar to what we did on the Apollo program. With commercial providers, I know that none will start from the beginning design of the launch vehicle for human rated requirements. As I pointed out, the Gemini Titan Program was a high risk demonstration program. We knew that certain areas of launch from the time of ignition throughout the launch profile and into orbit, would be hazardous if not fatal, if failure occurred.

With respect to the latter part of your fourth question, "Is there a risk of being in a situation where those emerging enterprises are deemed 'too important to fail' and we end up having to support them at whatever cost and time it takes", the answer is emphatically yes. Once the program starts and encounters major technical and cost difficulties it is very difficult to stop unless the program is cancelled.

Questions submitted by Representative Pete Olson

Q1. In your testimony you spoke briefly about the relationship between the President, the OMB, and the Congress in setting and carrying out our space programs. Would you please elaborate on what you see as the strengths, weaknesses, and potential problems impacting our nation's ability to carry out effective space policies?

A1. Ranking Member Olson—In answer to your question in relation to the President, OMB, and Congress in a setting to carry out the US Space program, the political forces have been very visible in the last 18 years vs. what is experienced from the start of the human space flight program. In the many times that I have testified in front of Congressional bodies (Senate and House), the most important issue I have emphasized is that we need is a long range strategic plan that the country can follow with only slight modifications. This fact was brought out vividly by the Columbia Accident Investigation Board.

My first recommendation to the Augustine Committee was to reestablish the National Space Council since it was written into law with the efforts of Senate Majority Leader, Lyndon Johnson, in 1958. Under this law, the President can enact the council and it worked extremely well during the Mercury, Gemini, and Apollo programs. It was also effective for four years under President George W. H. Bush. Without a strategic oversight group such as the National Space Council, you will have second level tier individuals like those in the OMB who makes major acts on programs. For example, I am sure that the President did not recognize at the time that an individual in 2004 told NASA that they have 15 flights to finish the Space Shuttle project by 2008 and this was during the time that the Space Shuttle was still grounded after the Columbia accident, which would result in the US buying launches from the Russians for many years. This is the same second tier level individual, at the OMB, who arbitrarily set the date at 2015 for the termination of US funding of this great international multi-partner laboratory and spacecraft, the ISS.

Questions submitted by Representative Dana Rohrabacher

Q1. There have been suggestions that a smaller, simpler vehicle designed just to access low Earth orbit and the International Space Station could be developed faster and less expensively than Orion. Furthermore, such a vehicle might be more easily lofted using either existing or modified EELV's. From your experi-

ence aboard the two-person Gemini spacecraft, do you see any reason why a smaller version of a capsule would be any simpler or less expensive to certify as human-rated?

A1. Mr. Rohrabacher—To provide a safe launch of a spacecraft on a rocket booster to orbit a human crew is always a major disciplined task. Whether you go beyond LEO or not, the same discipline would have to be followed whether the spacecraft is to fly to the moon or Mars, or only operate in only LEO, would require the same discipline to achieve LEO and safely return. A larger more complex spacecraft naturally costs more than a smaller spacecraft. We do not need as extensive systems and fuel as for a Mars spacecraft would require as compared to LEO.

My recommendation would be for the development of a crew module in a block series (i.e. Block I, II, III), LEO, Moon, or Mars mission. The smaller version would be only somewhat less expense to certify safety for a crew.

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