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NASA'S EXPLORATION INITIATIVE: STATUS AND ISSUES

HEARING

BEFORE THE

SUBCOMMITTEE ON SPACE AND AERONAUTICS

COMMITTEE ON SCIENCE AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED TENTH CONGRESS

SECOND SESSION

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April 3, 2008

NASA's EXPLORATION INITIATIVE: STATUS AND ISSUES

THURSDAY, APRIL 3, 2008

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

The Subcommittee met, pursuant to call, at 10:08 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Mark Udall [Chairman of the Subcommittee] presiding.

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

Hearing on

NASA's Exploration Initiative: Status and Issues

April 3, 2008
10:00 a.m. – 12:00 p.m.
2318 Rayburn House Office Building

WITNESS LIST

Dr. Richard Gilbrech
Associate Administrator
Exploration Systems Mission Directorate
NASA

Ms. Cristina T. Chaplain
Director
Acquisition and Sourcing Management
Government Accountability Office

Dr. Noel Hinners
Independent Consultant

Dr. Kathryn Thornton
Professor
Department of Science, Technology and Society,
Associate Dean
School of Engineering & Applied Science
University of Virginia

HEARING CHARTER

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

NASA's Exploration Initiative: Status and Issues

THURSDAY, APRIL 3, 2008
10:00 A.M.–12:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

Purpose

On Thursday, April 3, 2008 at 10:00 a.m., the House Committee on Science and Technology's Subcommittee on Space and Aeronautics will hold a hearing to review the status of the National Aeronautics and Space Administration's Exploration Initiative and examine issues related to its implementation.

Witnesses

Witnesses scheduled to testify at the hearing include the following:

Dr. Richard Gilbrech, Associate Administrator, Exploration Systems Mission Directorate, National Aeronautics and Space Administration

Ms. Cristina Chaplain, Director, Acquisition and Sourcing Management, Government Accountability Office

Dr. Noel Hinners, Independent Aerospace Consultant

Dr. Kathryn Thornton, Professor of Department of Science, Technology and Society; Associate Dean of the School of Engineering & Applied Science University of Virginia

Issues That May Be Raised at the Hearing

Implementing the *Vision for Space Exploration:*

- Does the exploration architecture, as laid out by NASA, present a technically and programmatically viable approach for executing exploration beyond low-Earth orbit under a pay-as-you-go strategy?
- Is the United States on the right track to reach the Moon by 2020, establish an outpost there, and eventually send humans to Mars, or do any changes need to be made to the architecture or implementation plan?
- How will progress in implementing the architecture be measured?
- How sustainable will NASA's planned exploration initiative be, given the assumed constrained budgetary outlook as well as the cutbacks in funding for long-lead exploration technology development?
- How has implementation of the VSE affected "the gap" in U.S. crew access to the International Space Station?

Status of Exploration Initiatives:

- Is NASA's strategy in designing the Orion CEV to first service the ISS and then upgrading it to enable lunar missions the most cost-effective approach? That is, is the upgrade approach, rather than designing a crewed vehicle capable of both missions at the onset, the most cost-effective approach?
- What is the status of NASA's Exploration Program and associated projects?
    - What would be the effect on the March 2015 Initial Operating Capability (IOC) date for Orion and Ares I if NASA is funded at the FY08 level required by a Continuing Resolution in FY09? Would this reduced level for Constellation Systems exacerbate the "gap" and if so, by how much?
    - Is it technically and programmatically possible to accelerate the Orion CEV's Initial Operating Capability (IOC) to a date earlier than March 2015 and still maintain a confidence level of 65 percent? What funding

beyond the President's request would be needed in FY09, FY10 and the out years to enable such acceleration? Would currently planned reviews and testing be retained during the acceleration?

- Will the March 2015 CEV IOC date slip if projected Shuttle retirement transition costs starting in FY 2011 exceed NASA's goal of less than $500 million?
- How close is NASA to resolving the Ares I thrust oscillation issue and will this issue have any impact on milestones leading up to the March 2015 IOC date?
- If additional resources are made available to NASA's Exploration Program, what should they be used for?

Strategies for lunar exploration, science as part of a lunar exploration program, and international and commercial participation:

- What are the most important objectives to be accomplished in returning humans to the Moon?
- To what extent are those objectives prerequisites for exploration beyond the Moon?
- What is NASA's plan and notional timeline for lunar exploration, and exploration beyond the Moon, once those objectives have been achieved?
- Is the current lunar exploration program adaptable to changes in national priorities and budgets?
- What are the decision points for further exploration beyond the Moon and what factors will inform those decisions?
- How should Congress ensure that the establishment of a lunar outpost does not divert attention and resources from exploration beyond the Moon, as articulated in the *Vision for Space Exploration* and the *NASA Authorization Act of 2005*? Does a lunar outpost need to be permanently occupied, or would a human-tended outpost be sufficient to meet exploration objectives?
- What is NASA's approach to achieving synergy between science and exploration, and is it effective?
    - How can lunar missions be focused to enable a high potential for scientific return?
    - Are there organizational issues that can impede this high potential for scientific return?
    - How does lunar science fit within the context of other planetary science priorities?
- What major issues need to be addressed before the United States can move forward on arranging international partnerships and commercial contributions to carry out the exploration of the Moon and other destinations, and how should those issues be addressed?
    - How important are such international partnerships and commercial contributions to the success of the exploration initiative?
    - How can international collaboration in NASA's exploration plans be enhanced? Is there a greater role the international community can play in lunar exploration? What cost implications would such international collaboration have on future NASA budgets?
    - What are the cost and programmatic implications of the U.S.'s plan to build the lunar transportation infrastructure, initial communication and navigation infrastructure, and initial surface EVA capability?
    - What have we learned about maximizing the effectiveness of international partnerships in the ISS program that could help us better understand how to carry out the exploration initiative?

BACKGROUND

Overview

In January 2004, President Bush announced his *Vision for Space Exploration* (VSE), 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, beginning with 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 space flight 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."*

With regards to milestones, the Act directed the Administrator to manage human space flight programs to strive to achieve the following milestones:

- *"Returning Americans to the Moon no later than 2020.*
- Launching the Crew Exploration Vehicle as close to 2010 as possible.
- Increasing knowledge of the impacts of long duration stays in space on the human body using the most appropriate facilities available, including the ISS.
- Enabling humans to land on and return from Mars and other destinations on a timetable that is technically and fiscally possible."

In September 2005, NASA released the results of the Agency's exploration architecture study—ESAS—a 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. According to GAO, NASA plans to spend nearly $230 billion over the next two decades implementing the VSE plans. Because of the funding needs of other NASA priorities, the agency has proceeded on a "pay as you go" scenario in implementing the VSE. This situation has been further exacerbated by Presidentially-requested agency budgets that have been less than those authorized by the Congress and less than those assumed in the multi-year plan following release of the VSE. However, inadequate funding is not NASA's only challenge in implementing the VSE.

NASA's plans to retire the Shuttle and complete the ISS by 2010 make the task of developing new systems more difficult. The resumption of Space Shuttle flights after the tragic loss of Shuttle *Columbia* has enabled significant progress in the assembly of the ISS. However, the pace of ISS assembly activities is also a reminder that such Shuttle flights will cease in 2010 at which time the U.S. will need to rely on partners such as Russia to provide routine transportation and emergency crew return from the ISS until the new Orion Crew Exploration Vehicle (CEV) achieves operational status. The period of time during which the U.S. has no crew transportation capability is referred to as "the gap." The European ATV supply vehicle recently flown to the ISS marks a significant new capability. Bringing propellant and supplies to the ISS, it is scheduled to dock on the date of this hearing. In addition, while NASA is encouraging the development of a commercial crew and cargo capability, the availability of such a capability is uncertain at this time. Thus, in addition to enabling future human lunar missions, the CEV has taken on a broader significance as the means of ensuring access by U.S. astronauts to low-Earth orbit once the Shuttle is retired.

Fiscal Year 2009 Budget Request

The President's proposal for NASA's FY09 budget provides $3.50 billion for the Exploration Systems Mission Directorate (ESMD). From a direct cost perspective,[1] the proposed FY09 budget for ESMD is an increase of $357.4 million from that appropriated in FY08. The ESMD budget funds the following:

- Constellation Systems. This includes the development, demonstration, and deployment of the Orion Crew Exploration Vehicle (CEV) and the Ares I Crew Launch Vehicle (CLV) as well as associated ground and in-orbit infrastructure. The proposed direct funding for the Constellation Systems Program for FY09 is $2,875.1 million—an increase from the $2,341.4 million enacted in FY08.
- Commercial Crew and Cargo. The proposed funding for Commercial Crew and Cargo for FY09 is $173 million—an increase of $42.5 million from that enacted in FY08. ESMD plans to complete its demonstration of Commercial Orbital Transportation Services (COTS) in FY10. The commercial procurement

[1] As part of the budget restructuring undertaken in the FY09 budget request, NASA shifted from a full-cost budget, in which each project budget included overhead costs, to a direct cost budget. All overhead budget estimates are now consolidated into the Cross Agency Support budget line. NASA has stated that maintaining a full cost budget with seven appropriations accounts would be overly complex and inefficient. The direct cost budget shows program budget estimates that are based entirely on program content. Individual project managers continue to operate in a full-cost environment, including management of overhead costs.

of low-Earth orbit transportation services (e.g., to the ISS) will be executed by the Space Operations Mission Directorate.

- Advanced Capabilities. The proposed funding for Advanced Capabilities for FY09 is $452.3 million, a decrease of $218.8 million from the $671.1 million enacted in FY08. Activities in Advanced capabilities include:
- Human research to support ISS and future exploration by investigating and mitigating risks to astronaut health and developing human space flight medical and human factors standards;
- Exploration Technology Development to support Orion and other exploration programs. Requested funding in FY09 for Exploration Technology Development has been reduced. Despite the critical role technology development plays in reducing the risks of future space travel, funding for technology development is $81.9 million less from that appropriated in FY08. Exploration Technology Development Program investments reduce the risk of infusing new technologies into flight projects by maturing them to the level of demonstration in a relevant environment; and
- A lunar precursor robotic program to provide knowledge of lunar environment and reduce the risk of crewed lunar landing.

Assumed Budget Growth for NASA Exploration FY 2009–FY 2013

The President's budget request for NASA's Exploration Systems Mission Directorate is assumed to grow significantly after the Space Shuttle is retired in late 2010. In addition to completing development and testing of Orion and Ares I, design work will begin in earnest on the Ares V heavy lift launcher and Altair lunar lander that will be used to return U.S. astronauts to the Moon by the end of the decade, according to NASA's plans.

$ in millions					
FY 2008 Enacted	FY2009 Request	FY 2010	FY2011	FY2012	FY2013
3,143.1	3,500.5	3,737.7	7,048.2	7,116.8	7,666.8

Exploration Systems Architecture Study

Shortly after Dr. Griffin was named the new NASA Administrator in April 2005, he set out to restructure the Exploration Program by making its priority to accelerate the development of the CEV to reduce or eliminate the planned gap in U.S. human access to space. Specifically, he established a goal for the CEV to begin operation in 2011[2] and to be capable of ferrying crew and cargo to and from the ISS; prior to his restructure, there were no plans for the CEV to service 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 and ease the transition after Space Shuttle retirement in 2010, the Administrator 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 Space Shuttle retirement, and eventually transporting humans to Mars. Under the 2005 ESAS plan, a Crew Exploration Vehicle (now called Orion) and Crew Launch Vehicle (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 serv-

[2] National Aeronautics and Space Administration (NASA), 2005, NASA's Exploration Systems Architecture Study, NASA–TM–2005–214062: 1–28

ices commercially. Lunar robotic precursor missions would begin immediately with the development and launch of the Lunar Reconnaissance Orbiter (LRO) mission and continue with a series of landing and orbiting probes to prepare for extended human lunar exploration. 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, leading to a human lunar landing in 2018. Starting in 2018, a series of short-duration lunar sortie missions would be accomplished, leading up to the deployment of a lunar outpost. The lunar surface systems (e.g., rovers, habitats, power systems) would be developed as required. Lunar missions would demonstrate the systems and technologies needed for eventual human missions to Mars.

This past February, the VSE was re-examined at a workshop co-sponsored by the Planetary Society and the Department of Aeronautics and Astronautics at Stanford University. The workshop brought together a group of space exploration experts, including scientists, former NASA officials, and some aerospace industry executives. While participants had differing views on the objectives of exploration, they concluded that:

- *"It is time to go beyond LEO with people as explorers. The purpose of sustained human exploration is to go to Mars and beyond. The significance of the Moon and other intermediate destinations is to serve as stepping stones on the path to that goal.*
- *Bringing together scientists, astronauts, engineers, policy analysts, and industry executives in a single conversation created an environment where insights across traditional boundaries occurred.*
- *Human space exploration is undertaken to serve national and international interests. It provides important opportunities to advance science, but science is not the primary motivation.*
- *Sustained human exploration requires enhanced international collaboration and offers the United States an opportunity for global leadership.*
- *NASA has not received the budget increases to support the mandated human exploration program as well as other vital parts of the NASA portfolio, including space science, aeronautics, technology requirements, and especially Earth observations, given the urgency of global climate change."*

Revisiting the Constellation Architecture

Subsequent to the issuance of ESAS, proposals have been made in support of alternative launch vehicle designs to those chosen by NASA. These have included proposals for a "Direct Derivative" of the existing Shuttle Transportation System and modified versions of the Evolved Expendable Launch Vehicle (EELV).

The Direct Derivative launch vehicle, publicized at the American Institute of Aeronautics and Astronautics' Space 2007 Conference and Exposition in September 2007, would make use of proven designs such as the main engines from the Delta-IV EELV and the solid rocket boosters used to launch the Shuttle. The proposed Direct Derivative would require two launches of the same launch vehicle; NASA's current architecture would require two launches using two different launch vehicles. In addressing the Space Transportation Association (STA) in January 2008, the NASA Administrator reviewed the architecture defined by ESAS and the reasons behind the choices made. After summarizing the requirements set forth by the President's *Vision for Space Exploration* and subsequent *NASA Authorization Act of 2005,* the Administrator stated that the requirement for a four-person sortie capability would require a vehicle with a trans-lunar injection (TLI) mass greater than that of the Saturn V and necessitate significant modifications to fabrication and launch infrastructure. The Administrator said that the projected NASA budget would not allow the development of extensive new ground infrastructure and after a detailed consideration of the single-launch option, the agency settled on a dual-launch Earth-orbit rendezvous (EOR) scheme. He then discussed several of the reasons that the ESAS team had for rejecting the Direct approach. The Administrator acknowledged that non-recurring costs would be lower because only one launch vehicle development is required. However, he said that the architectural approach of launching two identical vehicles carries significant liabilities when the broader requirements of NASA's policy framework are considered. In particular, he stated that a dual-launch EOR of identical vehicles is "vastly over-designed for ISS logistics," leading NASA to conclude that "dual-launch EOR with vehicles of similar payload class does not meet the requirement to support the ISS in any sort of cost-effective manner."

At that same speech, the Administrator acknowledged that the adoption of the Shuttle-derived approach of the Ares I CLV had been one of the more controversial decisions related to the exploration architecture. Among the reasons for NASA's developing the Ares I CLV instead of modifying existing EELVs, he identified insufficient lift capacity in existing EELVs, the absence of a growth path to heavy lift capability, and higher crew risk. In summary, he said that NASA's analysis showed *"EELV-derived solutions meeting the agency's performance requirements to be less safe, less reliable, and more costly than the Shuttle-derived Ares I and Ares V."*

Administrator Griffin's STA speech is included as an attachment to this hearing charter.

Status of Key Exploration Systems Initiatives and the "Gap"

Under the aegis of its Constellation Systems Program, NASA has initiated development of new space transportation capabilities including the Orion CEV, the Ares I CLV, spacesuits and tools required by the flight crews, and associated ground and mission operations infrastructure to support initial low-Earth orbit missions. Orion and Ares I are currently targeted to begin operational missions by March 2015.

The President's Vision statement directed NASA to have the CEV operational no later than 2014. Initially, since no plans were made for the CEV to service the ISS, international partner assets would be required to ferry U.S. crew and cargo to the ISS after 2010—creating a significant gap in domestic space access for U.S. astronauts. In its FY 2006 budget request, NASA said that its budget plan would deliver an operational CEV in 2014. The *NASA Authorization Act of 2005* directed the NASA Administrator to *"manage human space flight programs to strive to achieve . . . launching the Crew Exploration Vehicle as close to 2010 as possible"* subject to the proviso that the Administrator shall *"construct an architecture and implementation plan for NASA's human exploration program that is not critically dependent on the achievement of milestones by fixed dates."* Upon being named Administrator, Dr. Griffin restructured the Exploration Program by establishing a goal for the CEV to begin operation in 2011 by servicing the ISS. However, the FY 2007 budget request established a CEV initial operating date of no later than 2014. NASA subsequently concluded that *"As a result of this analysis over the past two months, the FY 2008 budget request does not support a 2014 initial operational capability, but March 2015, even before the FY07 CR impact . . ."* At last year's FY 2008 budget hearing before the Committee, the NASA Administrator said that while the reduction in funding caused by the 2007 Continuing Resolution extended the operational date to September of 2015, NASA terminated some lower priority activities to buy back some schedule for the CEV. This returned NASA to the March of 2015 date, four years later than the goal established in ESAS, thus leaving a "gap" of almost five years in U.S. space flight capability due to the retirement of the shuttle in 2010. The confidence level set by NASA of achieving the March 2015 date is 65 percent.

The FY09 budget request funds activity levels that maintain NASA's commitment to reach initial operating capability (IOC) for both Orion and Ares I by March 2015, although NASA acknowledges that it is striving to bring the new system on line sooner. Nevertheless, the FY09 budget request does not accelerate the initial operating capability date. This issue was brought up recently at the NASA FY09 budget hearing held before the Committee on February 13, 2008. At that time, Mr. Lampson asked whether a request had been made to OMB for additional funds to narrow the gap and if so, what happened. The NASA Administrator responded that *"we have many priorities, many funding priorities in the Nation, all of which clamor for first attention. And the funding, the priority of closing the gap between Shuttle retirement and deployment of new systems did not make it to the top."* NASA had previously indicated that accelerating the IOC date to 2013 would require an additional $1 billion per year in the years FY09 and FY10.

However, even meeting the target March 2015 date will require timely resolution of design issues that have surfaced, particularly in the Ares I program. An October 2007 GAO report on Ares I found that *"requirements instability," "technology and hardware development knowledge gaps,"* an *"aggressive schedule,"* and *"projected funding shortfalls"* represent significant challenges for the program. And recently, NASA has found that it needs to study the possibility of vibration in the Ares I launch vehicle. Depending on what changes might need to be made to mitigate this potential "thrust oscillation" issue, additional costs to both the Ares I launcher and Orion spacecraft may be needed to address this problem. According to NASA, the first test flight of the Ares launcher dubbed Ares I–Y is scheduled for the third quarter of FY09. At that time, a four-segment version of the final Ares I five-segmented launch vehicle will be tested while transporting a simulated payload.

Although NASA states that threats to the Orion and Ares I projects are being addressed through a rigorous risk management process, an area of concern is the level of reserves in the Constellation program that are available through FY10 due to its potential impact on NASA's ability to maintain its scheduled March 2015 operational date. These reserve levels are characterized by NASA as minimal—less than eight percent. In discussions with NASA, officials indicated that the $2 billion needed to accelerate the initial operational date would be primarily used to bolster reserves and thus allow the agency to address disruptive schedule problems as they occurred.

Major contractors supporting NASA in the development of Constellation systems currently include:

- Lockheed Martin for Orion (Current total contract value for Schedules A, B, and C: $8.55 billion)
- Pratt & Whitney Rocketdyne for Ares I upper stage engine (Current contract value: $1.2 billion)
- ATK Thiokol for Ares I first stage (Current contract value: $1.8 billion)
- Boeing for Ares I upper stage production (Current contract value: $514.7 million)
- Boeing for Ares I upper stage avionics production ($799.5 million)

Initial Lunar Exploration

The Lunar Precursor Robotic Program is currently the most visible evidence of NASA's lunar exploration activities. The proposed funding for the Lunar Precursor Robotic Program (LPRP) for FY09 is $56.3 million, a significant decrease from the $198.2 million enacted in FY08. The bulk of LPRP funding occurred in FY07 ($247.3 million). This program includes the Lunar Reconnaissance Orbiter (LRO), which will take high-resolution images of the Moon, map resources, and assess the lunar environment for future exploration, and the Lunar Crater Observation and Sensing Satellite (LCROSS), which will help confirm the presence or absence of water ice in a permanently shadowed crater at the Moon's South Pole. This is significant since such water, if discovered in sufficient quantities, potentially could be converted to rocket fuel and breathable oxygen facilitating the operation of a lunar base for astronauts. The combined LRO/LCROSS mission is scheduled to launch in late 2008 on an Atlas V. The spacecraft will be placed in low polar orbit for a one year mission managed by NASA's Exploration Systems Mission Directorate. Although the objectives of LRO are exploratory in nature, the payload includes instruments with heritage from previous planetary science missions, enabling transition, after one year, to a scientific phase under NASA's Science Mission Directorate.

Planning for future sustained lunar exploration is also well underway. NASA's Lunar Architecture envisions the construction of an outpost initially at a polar site on the Moon. Infrastructure needs such as power generation, habitation, mobility, navigation and communications, and complementary robotic missions are being defined.

Future Human Exploration of the Moon

The Exploration Systems Architecture provides the capability for up to four crew members to explore any site on the Moon for up to seven days. These missions, referred to as lunar sorties, are analogous to the Apollo surface missions and will demonstrate the capability to land humans on the Moon, have them operate for a limited period on the lunar surface, and safely return them to Earth.

Scheduled for 2020, the elements needed to perform the mission include Ares I, Orion (possibly a modification of the version used to access the ISS), the Ares V Cargo Launch Vehicle, the Altair lunar lander, and an Earth Departure Stage vehicle. The lunar lander and Earth Departure Stage vehicle will be pre-deployed in low-Earth orbit using the Ares V vehicle. Ares I will deliver Orion and its crew to low-Earth orbit, where the two vehicles will rendezvous and dock. Upon reaching the Moon, the entire crew will then transfer to Altair, undock from Orion, and perform a descent to the lunar surface. After up to seven days on the lunar surface, the Altair ascent stage will return the crew to lunar orbit where they will dock with Orion. After transferring back to Orion, the crew will then return to Earth.

NASA's Lunar Architecture envisions extended missions in the future. The agency recently updated its architecture. Human lunar missions will be used to build an outpost initially at a polar site. This will require the establishment of power generation, habitation, means for mobility such as rovers, and navigation and communication. NASA's intent is to develop the infrastructure while actively being engaged in science and exploration. Efforts are underway by NASA to take a leadership role in establishing an "open architecture" for lunar exploration, which it envisions as conducive to international cooperation.

International Collaboration in Space Exploration

The U.S. and several other nations have sent or are planning to send robotic missions to the Moon. This has elevated the need for a globally coordinated strategy for exploration. In May 2007, 14 space agencies released the results of 12 months of discussion—The Framework for Coordination—as part of an overall Global Exploration Strategy. The Framework is a vision for robotic and human space exploration, focusing on destinations within the solar system where humans may one day live and work. The Framework does not propose a single global exploration program. Instead, it recommends a mechanism through which nations can collaborate to strengthen both individual projects and collective efforts. The Framework includes an action plan for coordinating strategies to help space-faring nations reach their exploration goals more effectively and safely. In addition, the Framework recognizes that a partnership between humans and robots is essential to the success of space exploration. The strength in robotic spacecraft lies in their ability to be scouts and venture into hostile environments. Humans, on the other hand, bring flexibility, experience, and problem-solving skills. In addition, NASA and the European Space Agency initiated an architecture assessment in January 2008 to outline potential collaborative scenarios using their respective human and robotic exploration capabilities. The goal is to identify by May 2008 potential future collaborative scenarios utilizing respective human/robotic exploration capabilities.

Attachment 1

The Constellation Architecture

MICHAEL D. GRIFFIN
ADMINISTRATOR
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
REMARKS TO THE
SPACE TRANSPORTATION ASSOCIATION

22 JANUARY 2008

As those who have attended any speech I've given know, I don't read well in public. Everyone seems to enjoy the interactive sessions that typically follow somewhat more. However, I wanted my thoughts on this topic to be available on the written record, so if my remarks this morning come across as an engineering lecture, then I have succeeded. I hope you all had a strong cup of coffee. Today's topic is motivated by the inquiries I've had lately, in one forum or another, concerning various aspects of NASA's post-Shuttle space flight architecture. None of the questions is new, and all of them were elucidated during our Exploration Systems Architecture Study (ESAS). The architecture is essentially as it was coming out of ESAS back in September 2005, and the architectural trades we made then when considering mission requirements, operations concepts, performance, risk, reliability, and cost hold true today. But more than two years have gone by, and the logic behind the choices we made has receded into the background. People come and go, new questioners lacking subject matter background appear, and the old questions must be answered again if there is to be general accord that NASA managers are allocating public funds in a responsible fashion. And so it seemed to me that the time was right to review, again, why we are developing the post-Shuttle space architecture in the way that we are.

As many of you know, I used to teach space system engineering at George Washington University and the University of Maryland, and am more comfortable discussing engineering design than just about any other topic. But as NASA Administrator, I must first frame the Constellation architecture and design in the context of policy and law that dictate NASA's missions.

Any system architecture must be evaluated first against the tasks which it is supposed to accomplish. Only afterwards can we consider whether it accomplishes them efficiently, or presents other advantages which distinguish it from competing choices. So to start, we need to review the requirements expressed in Presidential policy and, subsequently, Congressional direction, that were conveyed to NASA in 2004 and 2005.

The principal documents pertinent to our architecture are President Bush's January 14th, 2004 speech outlining the *Vision for Space Exploration,* and the *NASA Authorization Act of 2005.* Both documents are a direct result of the policy debate that followed in the wake of the *Columbia* tragedy five years ago, and the observation of the *Columbia* Accident Investigation Board (CAIB), "The U.S. civilian space effort has moved forward for more than thirty years without a guiding vision." Several items of specific direction are captured in the President's speech: "Our first goal is to complete the International Space Station by 2010. We will finish what we have started, we will meet our obligations to our 15 international partners on this project." "Research on board the station and here on Earth will help us better understand and overcome the obstacles that limit exploration. Through these efforts we will develop the skills and techniques necessary to sustain further space exploration." "Our second goal is to develop and test a new spacecraft, the Crew Exploration Vehicle, . . . and to conduct the first manned mission no later than 2014. The Crew Exploration Vehicle will be capable of ferrying astronauts and scientists to the Space Station after the shuttle is retired. But the main purpose of this spacecraft will be to carry astronauts beyond our orbit to other worlds." "Our third goal is to return to the Moon by 2020 . . ." "With the experience and knowledge gained on the Moon, we will then be ready to take the next steps of space exploration: human missions to Mars and to worlds beyond." After extensive debate, the Congress offered strong bipartisan approval of these goals, while adding considerable specificity. From the 2005 Authorization Act for NASA, "The Administrator shall 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 shall manage human space flight programs to strive to achieve the following milestones, (A) Returning Americans to the Moon no later than 2020. (B) Launching the Crew Exploration Vehicle as close to 2010 as possible. (C) Increasing knowledge of the impacts of long duration stays in space on the human body using the most appropriate facilities available, including the ISS. (D) Enabling humans to land on and return from Mars and other destinations on a timetable that is technically and fiscally possible." The bill establishes specific requirements for the International Space Station, noting that it must "have an ability to support a crew size of at least six persons," codifying a long-promised design feature in law. It also details statutory requirements for Shuttle transition, including maximizing the use of Shuttle assets and infrastructure:

> *"The Administrator shall, to the fullest extent possible consistent with a successful development program, use the personnel, capabilities, assets, and infrastructure of the Space Shuttle program in developing the Crew Exploration Vehicle, Crew Launch Vehicle, and a heavy-lift launch vehicle."*

Collectively, these requirements outline the broad policy framework for the post-Shuttle U.S. human space flight architecture: We will manage the U.S. space program so as to complete the International Space Station by 2010, utilizing the Space Shuttle for that purpose, after which it will be retired. After completion, the ISS will be used to "better understand and overcome the obstacles that limit exploration." The Shuttle will be replaced as soon as possible, but not later than 2014, by a Crew Exploration Vehicle designed to take humans to the Moon and beyond, but which must also be capable of servicing the ISS and its crew of six. The architecture must support human lunar return not later than 2020 and, after that, development of a sustained human lunar presence, both for its intrinsic benefits and as a "stepping stone" to Mars and beyond. Finally, the new architecture must take advantage of existing Space Shuttle program assets "to the fullest extent possible." Not that anyone asked, but I consider this to be the best civil space policy to be enunciated by a president, and the best Authorization Act to be approved by the Congress, since the 1960s. But no policy is perfect, and none will please everyone. In particular, many in the exploration community, as well as many of those who pursue space science, were disappointed by the reaffirmation of our nation's commitment to the ISS.

But a plain reading of policy and law requires us to understand that, throughout four presidential administrations and twenty-plus Congressional votes authorizing tens of billions of dollars for its development, the ISS has remained an established feature of U.S. space policy. Its support and sustenance cannot be left to chance; the CEV must and will be capable of fulfilling this requirement, and the exploration architecture must and will take that into account. This is nothing more than common sense. The U.S. government will not abandon its commitment to the development and utilization of low-Earth orbit (LEO). There continue to be many questions about NASA's long-term commitment to ISS, so let me clarify. The Bush Administration has made no decision on the end date for ISS operations. We are, of course, concerned that Station operating costs after 2016 will detract from our next major milestone, returning to the Moon by 2020. But while the budget does not presently allocate funds for operating ISS beyond 2016, we are taking no action to preclude it. Decisions regarding U.S. participation in ISS operations after 2016 can only be made by a future Administration and a future Congress. I am sure these will be based on discussions with our international partners, progress toward our Exploration goals, utility of this national laboratory, and the affordability of projected ISS operations. Again, we plan to keep our commitments to our partners, utilizing ISS if it makes sense. Now, returning to our space architecture, note the order of primacy in requirements. We are *not* primarily building a system to replace the Shuttle for access to LEO, and upgrading it later for lunar return. Instead, we are directed to build a system to "carry astronauts beyond our orbit to other worlds," but which can be put to the service of the ISS if needed. In brief, we are designing for the Moon and beyond. That too is only common sense. Once before, an earlier generation of U.S. policy-makers approved a space flight architecture intended to optimize access to LEO. It was expected—or maybe "hoped" is the better word—that, with this capability in hand, the tools to resume deep space exploration would follow. It didn't happen, and with the funding which has been allocated to the U.S. civil space program since the late 1960s, it cannot happen. Even though from an engineering perspective it would be highly desirable to have transportation systems separately optimized for LEO and deep space, NASA's budget will not support it. We get one system; it must be capable of serving in multiple roles, and it must be designed for the more difficult of those roles from the outset. There are other common-sense requirements which have not been written down. The most obvious of these, to me, is that the new system will and should be in use for many decades. Aerospace systems are expensive and difficult to develop; when such developments are judged successful, they tend to remain in use far longer than one might at first imagine. Those who doubt this should look around. The DC–3 and the B–52, to name only two landmark aircraft, remain in service today. The Boeing 747 has been around for thirty years, and who doubts that it will be going strong for another thirty? In space, derivatives of Atlas and Delta and Soyuz are flying a half-century and more after their initial development. Ariane and its derivatives have been around for three decades, with no end in sight. Even the Space Shuttle will have been in service for thirty years by the time it retires. Apart from *Saturn/Apollo,* I am hard put to think of a successful aerospace system which was retired with less than several decades of use, and often more. The implications of this are profound. We are designing today the systems that our grandchildren will use as building blocks, not just for lunar return, but for missions to Mars, to the near-Earth asteroids, to service great observatories at SunEarth L1, and for other purposes we have not yet even considered. We need a system with inherent capability for growth. Elsewhere, I have written that a careful analysis of what we can do at NASA on constant-dollar budgets leads me to believe that we can realistically be on Mars by the mid-2030's. It is not credible to believe that we will return to the Moon and then start with a "clean sheet of paper" to design a system for Mars. That's just not fiscally, technically or politically realistic. We'll be on Mars in thirty years, and when we go, we'll be using hardware that we're building today. So we need to keep Mars in mind as we work, even now. And that means we need to look at both ends of the requirements spectrum. Our new system needs to be designed for the Moon, but allow U.S. government access to LEO. Yet, in designing for the Moon, we need also to provide the maximum possible "leave behind" for Mars. If we don't, then a generation from now there will be a group in this room, listening to the Administrator of that time ask, about those of us here today, "what were they thinking?" Now, in mentioning "Mars" I must state for the record that I do realize that the $550 billion *Consolidated Appropriations Act* signed into law last month stipulated that no funds appropriated in 2008 "shall be used for any research, development, or demonstration activities related exclusively to the human exploration of Mars." While I personally consider this to be shortsighted, and while NASA was in any case spending only a few million dollars on long-term research and study efforts, we will of course follow this legislative direction. And while this provision does not affect work on *Ares V,* it does call into question the fundamental rationale for our use of Space Station in long-duration human space flight research. I hope that this funding restriction can be abandoned in future years. Further application of common sense also requires us to acknowledge that now is the time, this is the juncture, and we are the people to make provisions for the contributions of the commercial space sector to our nation's overall space enterprise. The development and exploitation of space has, so far, been accomplished in a fashion that can be described as "all government, all the time." That's not the way the American frontier was developed, it's not the way this nation developed aviation, it's not the way the rest of our economy works, and it ought not to be good enough for space, either. So, pro-actively and as a matter of deliberate policy, we need to make provisions for the first step on the stairway to space to be occupied by commercial entrepreneurs—whether they reside in big companies or small ones. The policy decision that the CEV will be designed for the Moon, while not precluding its ability to provide access to LEO, strongly reinforces this common sense objective. If designed for the Moon, the use of the CEV in LEO will inevitably be more expensive than a system designed for the much easier requirement of LEO access and no more. This lesser requirement is one that, in my judgment, can be met today by a bold commercial developer, operating without the close oversight of the U.S. Government, with the goal of offering transportation for cargo *and crew* to LEO on a fee-for-service basis. This is a policy goal—enabling the development of commercial space transportation to LEO—that *can* be met if we in government are willing to create a protected niche for it. To provide that niche, we must set the requirements for the next-generation government space flight system at the lunar-transportation level, well above the LEO threshold. Now again, common sense dictates that we cannot hold the ISS hostage to fortune; we cannot gamble the fate of a multi-tens-of-billions-of-dollar facility on the success of a commercial operation, so the CEV must be able to operate efficiently in LEO if necessary. But we can create a clear financial incentive for commercial success, based on the financial disincentive of using government transportation to LEO at what will be an inherently higher price. To this end, as I have noted many times, we must be willing to defer the use of government systems in favor of commercial services, as and when they reach maturity. When commercial capability comes on line, we will reduce the level of our own LEO operations with *Ares/Orion* to that which is minimally necessary to preserve capability, and to qualify the system for lunar flight. So how is all of this—law, policy, and common sense—realized in the architecture that came out of ESAS? As I have outlined above, policy and legislation are in some ways quite specific about the requirements for post-Shuttle U.S. space flight systems. They are less so where it concerns our lunar goals, beyond the clearly stated requirement to develop the capability to support a sustained human lunar presence, both for its intrinsic value and as a step toward Mars. This leaves considerably more discretion to NASA as the executive agency to set requirements, and with that considerably more responsibility to get it right. Again, I think common sense comes to our rescue. There is general agreement that our next steps to the Moon, toward a goal of sustained lunar presence, must offer something more than Apollo-class capability; e.g., sorties by two people for three days to the equatorial region. To return after fifty years with nothing more than the capability we once threw away, seems to me to fail whatever test of common sense might be applied to ourselves and our successors. Accordingly, then, in developing requirements for ESAS we specified that the lunar architecture should be capable of the following:

– Initial lunar sortie missions should be capable of sustaining a crew of four on the lunar surface for a week.
– The architecture will allow missions to any location on the Moon at any time, and will permit return to Earth at any time.
– The architecture will be designed to support the early development of an "outpost" capability at a location yet to be specified, with crew rotations planned for six-month intervals.

One could fill pages debating and justifying these requirements; mercifully, I will not do that. Perhaps another time. In any case, I think it is clear that these goals offer capability significantly beyond Apollo, yet can be achieved with the building blocks—ground facilities as well as space transportation elements—that we have or can reasonably envision, given the budgetary resources we might expect. It is worth noting that the decision to focus on early development of an outpost—while retaining the capability to conduct a dedicated sortie mission to any point on the lunar surface that might prove to be of interest for scientific or other reasons—supports additional key goals. The most obvious of these is that it provides a more direct "stepping stone" to Mars, where even on the very first mission we will need to live for an extended period on another planetary surface. But further, even a basic human-tended outpost requires a variety of infrastructure that is neither necessary nor possible to include in a sortie mission. Such infrastructure development presents obvious possibilities for commercial and international partner involvement, both of which constitute important policy objectives. But if the capability we are striving for is greater than that of Apollo, so too is the difficulty. To achieve the basic four-person lunar sortie capability anytime, anywhere, requires a trans-lunar injection (TLI) mass of 70–75 metric tons (mT), including appropriate reserve. *Saturn V* TLI capability on Apollo 17 was 47 mT without the launch adaptor used to protect the lunar module. Thus, more than *Saturn V* capability is required if we are to go beyond Apollo. I think we should not be surprised to find that the Apollo engineers got just about as much out of a single launch of the *Saturn V* as it was possible to do. If we need more capability to TLI than can be provided by a single launch of a *Saturn*-class vehicle, we can reduce our objectives, build a bigger rocket, or attain the desired capability by launching more than one rocket. Setting a lesser objective seems inconsistent with our goal of developing the capability for a sustained lunar presence, and, as noted earlier, merely replicating Apollo-era capability is politically untenable. Building a larger rocket is certainly an attractive option, at least to me, but to reach the capability needed for a single launch brings with it the need for significant modifications to fabrication and launch infrastructure. The Michoud Assembly Facility and the Vertical Assembly Building were designed for the *Saturn V,* and have some growth margin above that. But they will not accommodate a vehicle that can support our goals for lunar return with a single launch, and the projected NASA budget does not allow the development of extensive new ground infrastructure. Further, and crucially, a single-launch architecture fails to address the requirement for ISS logistics support. Thus, after detailed consideration of the single-launch option, we settled on a dual-launch Earth-orbit rendezvous (EOR) scheme as the means by which a TLI payload of the necessary size would be assembled. However, the decision to employ EOR in the lunar transportation architecture implies nothing about how the payload should be split. Indeed, the most obvious split involves launching two identical vehicles with approximately equal payloads, mating them in orbit, and proceeding to the Moon. When EOR was considered for Apollo, it was this method that was to be employed, and it offers several advantages. Nonrecurring costs are lower because only one launch vehicle development is required, recurring costs are amortized over a larger number of flights of a single vehicle, and the knowledge of system reliability is enhanced by the more rapid accumulation of flight experience. However, this architectural approach carries significant liabilities when we consider the broader requirements of the policy framework discussed earlier. As with the single-launch architecture, dual-launch EOR of identical vehicles is vastly over-designed for ISS logistics. It is one thing to design a lunar transportation system and, if necessary, use it to service ISS while accepting some reduction in cost-effectiveness relative to a system optimized for LEO access. As noted earlier, such a plan backstops the requirement to sustain ISS without offering government competition in what we hope will prove to be a commercial market niche. But it is quite another thing to render government logistics support to ISS so expensive that the Station is immediately judged to be not worth the cost of its support. Dual-launch EOR with vehicles of similar payload class does not meet the requirement to support the ISS in any sort of cost-effective manner. On the other end of the scale, we must judge any proposed architecture against the requirements for Mars. We aren't going there now, but one day we will, and it will be within the expected operating lifetime of the system we are designing today. We know already that, when we go, we are going to need a Mars ship with a LEO mass equivalent of about a million pounds, give or take a bit. I'm trying for one-significant-digit accuracy here, but think "Space Station," in terms of mass. I hope we're smart enough that we never again try to place such a large system in orbit by doing it in twenty-ton chunks. I think we all understand that fewer launches of larger payloads requiring less on-orbit integration are to be preferred. Thus, a vehicle in the *Saturn V* class—some 300,000 lbs in LEO—allows us to envision a Mars mission assembly sequence requiring some four to six launches, depending on the packaging efficiency we can attain. This is something we did once and can do again over the course of a few months, rather than many years, with the two heavy-lift pads available at KSC Complex 39. But if we split the EOR lunar architecture into two equal but smaller vehicles, we will need ten or more launches to obtain the same Mars-bound payload in LEO, and that is without assuming any loss of packaging efficiency for the launch of smaller payloads. When we consider that maybe half the Mars mission mass in LEO is liquid hydrogen, and if we understand that the control of hydrogen boil-off in space is one of the key limiting technologies for deep space exploration, the need to conduct fewer rather than more launches to LEO for early Mars missions becomes glaringly apparent. So if we want a lunar transportation architecture that looks back to the ISS LEO logistics requirement, and forward to the first Mars missions, it becomes apparent that the best approach is a dual-launch EOR mission, but with the total payload split unequally. The smaller launch vehicle puts a crew in LEO every time it flies, whether they are going to the ISS or to the Moon. The larger launch vehicle puts the lunar (or, later, Mars) cargo in orbit. After rendezvous and docking, they are off to their final destination. Once the rationale for this particular dual-launch EOR scenario is understood, the next question is, logically, "why don't we use the existing EELV fleet for the smaller launch?" I'm sure you will understand when I tell you that I get this question all the time. And frankly, it's a logical question. I started with that premise myself, some years back. To cut to the chase, it will work—as long as you are willing to define *"Orion"* as that vehicle which can fit on top of an EELV. Unfortunately, we can't do that. The adoption of the Shuttle-derived approach of *Ares I,* with a new lox/hydrogen upper stage on a reusable solid rocket booster (RSRB) first stage, has been one of our more controversial decisions. The *Ares V* heavy-lift design, with its external-tank-derived core stage augmented by two RSRBs and a new Earth departure stage (EDS), has been less controversial, but still not without its detractors. So let me go into a bit of detail concerning our rationale for the Shuttle-derived approach. The principal factors we considered were the desired lift capacity, the comparative reliability, and the development and life cycle costs of competing approaches. Performance, risk, and cost—I'm sure you are shocked. The *Ares I* lift requirement is 20.3 mT for the ISS mission and 23.3 mT for the lunar mission. EELV lift capacity for both the Delta IV and Atlas V are insufficient, so a new RL–10 powered upper stage would be required, similar to the J–2X based upper stage for *Ares I.* We considered using additional strap-on solid rocket boosters to increase EELV performance, but such clustering lowers overall reliability. It is also important to consider the growth path to heavy lift capability which results from the choice of a particular launch vehicle family. Again, we are designing an architecture, not a point solution for access to LEO. To grow significantly beyond today's EELV family for lunar missions requires essentially a "clean sheet of paper" design, whereas the *Ares V* design makes extensive use of existing elements, or straightforward modifications of existing elements, which are also common to *Ares I.* Next up for consideration are mission reliability and crew risk. EELVs were not originally designed to carry astronauts, and various human-rating improvements are required to do so. Significant upgrades to the Atlas V core stage are necessary, and abort from the Delta IV exceeds allowable g-loads. In the end, the probabilistic risk assessment (PRA) derived during ESAS indicated that the Shuttle-derived *Ares I* was almost twice as safe as that of a human-rated EELV. Finally, we considered both development and full life cycle costs. I cannot go into the details of this analysis in a speech, and in any case much of it involves proprietary data. We have shared the complete analysis with the DOD, various White House staff offices, CBO, GAO, and our Congressional oversight committees. Our analysis showed that for the combined crew and heavy-lift launch vehicles, the development cost of an EELV-derived architecture is almost 25 percent higher than that of the Shuttle-derived approach. The recurring cost of the heavy-lift *Ares V* is substantially less than competing approaches, and the recurring cost of an EELV upgraded to meet CEV requirements is, at best, comparable to that for *Ares I.* All independent cost analyses have been in agreement with these conclusions. So, while we might wish that "off the shelf" EELVs could be easily and cheaply modified to meet NASA's human space flight requirements, the data say otherwise. Careful analysis showed EELV-derived solutions meeting our performance requirements to be less safe, less reliable, and more costly than the Shuttle-derived *Ares I* and *Ares V.*

Now is a good time to recall that all of the trades discussed above assumed the use of a production version of the Space Shuttle Main Engine (SSME). But, returning to a point I made earlier, we continued our system analysis following the architecture definition of ESAS, looking for refinements to enhance performance and reduce risk and cost. We decided for *Ares I* to make an early transition to the five-segment RSRB, and to eliminate the SSME in favor of the J–2X on the upper stage. Similarly, elimination of the SSME in favor of an upgraded version of the USAF-developed RS–68 engine for the *Ares V* core stage, with the EDS powered by the J–2X, offered numerous benefits. These changes yielded several billion dollars in life cycle cost savings over our earlier estimates, and foster the use of a common RS–68 core engine line for DOD, civil, and commercial users. Praise is tough to come by in Washington, so I was particularly pleased with the comment about our decision on the five-segment RSRB and J–2X engine in the recent GAO review: "NASA has taken steps toward making sound investment decisions for *Ares I*." Just for balance, of course, the GAO also provided some other comments. So, for the record, let me acknowledge on behalf of the entire Constellation team that, yes, we do realize that there remain "challenging knowledge gaps," as the GAO so quaintly phrased it, between system concepts today and hardware on the pad tomorrow. Really. We do.

It's time now for a little perspective. We are developing a new system to bring new capabilities to the U.S. space program, capabilities lost to us since the early 1970s. It isn't going to be easy. Let me pause for a moment and repeat that. *It isn't going to be easy.* Did any of you here today *think* it was going to be easy? May I see a show of hands? How many of you thought we were going to re-create a capability for the United States to go to the Moon, a capability well beyond Apollo, and do it without any development problems? Anyone? So, no, we don't yet have all the answers to the engineering questions we will face, and in some cases we don't even know what those questions will be. That is the nature of engineering development. But we are going to continue to follow the data in our decision-making, continue to test our theories, and continue to make changes if necessary.

We have been, I think, extraordinarily open about all of this. Following the practice I enunciated in my first all-hands on my first day as Administrator, in connection with the then-pressing concerns about Shuttle return-to-flight, we are resolved to listen carefully and respectfully to any technical concern or suggestion which is respectfully expressed, and to evaluate on their merits any new ideas brought to us. We are doing that, every day. We will continue to do it. So, in conclusion, this is the architecture which I think best meets all of the requirements of law, policy, budget, and common sense that constrain us the post-Shuttle era. It certainly does not satisfy everyone, not that I believe that goal to be achievable. To that point, one of the more common criticisms I receive is that it "looks too much like Apollo." I'm still struggling to figure out why, if indeed that is so, it is bad. My considered assessment of the Constellation Architecture is that while we will encounter a number of engineering design problems as we move forward, we are not facing any showstoppers. Constellation is primarily a systems engineering and integration effort, based on the use of as many flight-proven concepts and hardware as possible, including the capsule design of *Orion,* the Shuttle RSRBs and External Tank, the Apollo-era J–2X upper stage engine, and the RS–68 core engine. We're capitalizing on the Nation's prior investments in space technology wherever possible. I am really quite proud of the progress this multi-disciplinary, geographically dispersed, NASA/industry engineering team has made thus far. But even so, the development of new systems remains hard work. It is not for the faint of heart, or those who are easily distracted. We can do it if, but only if, we retain our sense of purpose. In this regard, I'm reminded of two sobering quotes from the CAIB report. First, "the previous attempts to develop a replacement vehicle for the aging Shuttle represent a failure of national leadership." Also, the Board noted that such leadership can only be successful "if it is sustained over the decade; if by the time a decision to develop a new vehicle is made there is a clearer idea of how the new transportation system fits into the Nation's overall plans for space; and if the U.S. Government is willing at the time a development decision is made to commit the substantial resources required to implement it." That sort of commitment is what the mantle of leadership in space exploration means, and the engineers working to build Constellation know it every day. Thus, I can only hope to inspire them, and you, with the immortal words of that great engineer, Montgomery Scott, of the USS Enterprise: "I'm givin' 'er all she's got, Captain."

Thank you.

Chairman UDALL. Good morning. This hearing will come to order. And good morning. I want to welcome our witnesses, and I look forward to your testimony.

Today's hearing continues the Subcommittee's oversight of NASA's major program areas and will focus on the Agency's exploration initiative.

In many ways, NASA's Exploration Initiative exemplifies both the strengths and weaknesses of the Agency at this point in its history.

Begun in 2004 to implement the President's *Vision for Space Exploration,* NASA's initiative was conceived to be a broad and sustained program of human and robotic exploration of the solar system.

It was to be a step-by-step approach to exploration, starting with the completion of the International Space Station and subsequent retirement of the Space Shuttle, development of a new human space transportation system, and a return to the Moon as an initial step in a long-term journey to explore the solar system. It was also to include an ambitious set of robotic exploration activities and scientific investigations.

Yet from its beginning, NASA's Exploration Initiative has suffered from chronic under-funding, with a once-in-a-generation project to develop a new space transportation system shoe-horned into a NASA budget that in some years hasn't even kept pace with inflation.

That same under-funding has led to cutbacks in the Space Station research and critical exploration technology investments that will be needed if NASA's initiative is to go beyond simply being simply a repeat of the 1960's era Apollo project, albeit on a somewhat larger scale.

This is in no way a criticism of the dedicated NASA team that is developing the systems needed to take America's astronauts beyond low-Earth orbit.

They are working hard to make the best of a tough situation, and we want them to succeed. To that end, today we will hear from NASA about what has been accomplished to date, and we will examine what NASA is going to have to do to bring those new systems into operation.

Yet we also have to take a hard look at what it is going to take to make the initiative both sustainable and worth the money.

A good number of my colleagues agree with me that we should be investing more in NASA, but there isn't necessarily a consensus on what those funds should be used to accomplish.

For example, I think exploration is a worthwhile endeavor, and I do support it. However, it is also clear to me that NASA's core missions in aeronautics and science, especially Earth science and climate research, are highly relevant to addressing the Nation's needs and must be better supported than they have been.

Thus, if the next Administration keeps NASA's budget as constrained as it has been under this Administration, and I certainly hope it doesn't, then the pace of exploration is going to have to be adjusted to ensure that NASA's other important activities do not wind up being cannibalized.

Yet, whether or not NASA gets more money, we also need to ensure that the money NASA does get is spent as effectively as possible. Thus, at a minimum, NASA needs to follow good program management practices and do its best to control costs, something the GAO witness will discuss.

NASA also needs to do a better job of keeping Congress informed of its progress on critical initiatives so we can determine if they are proceeding in the right way and on budget.

In addition, it means that we need to make sure that NASA's program is structured in a way that ensures that the critical long-term exploration research and technology investments will be made.

It also means that we need to ensure that the activities we carry out on the Moon don't become a counterproductive drain on NASA's and the Nation's resources but instead help further our long-term exploration goals.

Finally, it means we need to ensure that we don't succumb to a temptation to rerun a space race that we already won nearly 40 years ago. Instead I think we need to be reaching out to fashion a new, internationally cooperative approach to exploration.

That, more than any nationalistically driven competition, will ensure that U.S. leadership in space is maintained in a way that will deliver the maximum benefits to our citizens for decades to come.

We have got a great deal to discuss today, and we have an expert panel to help us sort through all of these issues.

I again want to welcome you, and we appreciate your willingness to testify before us today.

[The prepared statement of Chairman Udall follows:]

PREPARED STATEMENT OF CHAIRMAN MARK UDALL

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Yet from its beginning, NASA's Exploration initiative has suffered from chronic underfunding, with a "once-in-a-generation" project to develop a new space transportation system "shoe-horned" into a NASA budget that in some years hasn't even kept pace with inflation.

That same underfunding has led to cutbacks in the Space Station research and critical exploration technology investments that will be needed if NASA's Exploration initiative is to go beyond simply being simply a repeat of the 1960's era Apollo project, albeit on a somewhat larger scale.

This is in no way a criticism of the dedicated NASA team that is developing the systems needed to take American astronauts beyond low-Earth orbit.

They are working hard to make the best of a tough situation, and we want them to succeed.

To that end, today we will hear from NASA about what has been accomplished to date, and we will examine what NASA is going to have to do to bring those new systems into operation.

Yet we also have to take a hard look at what it's going to take to make the Exploration initiative both sustainable and worth the money.

A good number of my colleagues agree with me that we should be investing more in NASA—but there isn't necessarily a consensus on what those funds should be used to accomplish.

For example, I think exploration is a worthwhile endeavor, and I support it.

However, it is also clear to me that NASA's core missions in aeronautics and science—and especially Earth science and climate research—are highly relevant to addressing the Nation's needs and must be better supported than they have been.

Thus, if the next Administration keeps NASA's budget as constrained as it has been under *this* Administration—and I hope it doesn't—then the pace of Exploration is going to have to be adjusted to ensure that NASA's other important activities do not wind up being cannibalized.

Yet, whether or not NASA gets more money, we also need to ensure that the money NASA does get is spent as effectively as possible.

Thus, at a minimum, NASA needs to follow good program management practices and do its best to control costs, something the GAO witness will discuss.

NASA also needs to do a better job of keeping Congress informed of its progress on critical initiatives, so we can determine if they are proceeding in the right way and on budget.

In addition, it means that we need to make sure that NASA's Exploration Program is structured in a way that ensures that the critical long-term exploration research and technology investments will be made.

It also means that we need to ensure that the activities we carry out on the Moon don't become a counterproductive drain on NASA's—and the Nation's—resources but instead help further our long-term exploration goals.

Finally, it means we need to ensure that we don't succumb to the temptation to rerun a "space race" that we won nearly forty years ago. Instead I think we need to be reaching out to fashion a new, internationally cooperative approach to exploration.

That, more than any nationalistically driven competition, will ensure that U.S. leadership in space is maintained in a way that will deliver the maximum benefits to our citizens for decades to come.

Well, we have a great deal to discuss today, and we have an expert panel to help us sort through all of these issues.

I again want to welcome you, and we appreciate your willingness to testify before us today.

Chairman UDALL. The Chair now recognizes Mr. Feeney for an opening statement, the Ranking Member.

Mr. FEENEY. Thank you, Mr. Chairman. I am grateful for your holding today's important hearing on NASA's Exploration Initiative. I also want to thank all of our witnesses for coming, one of whom is wearing a proud Florida Gators cap, and we are always glad to see Florida Gators here in our presence.

Your perspectives and expertise are immensely valuable as we carry our oversight responsibilities and prepare legislation to reauthorize NASA.

Human space exploration defines America as the world's preeminent space-faring Nation. Images of Shuttle and Apollo are deeply engrained in American culture, both our domestic version and the version exported to the rest of the world. Thousands, sometimes hundreds of thousands, of Americans and foreigners come to Florida's Space Coast to witness a Shuttle launch. And for the latest launch held at 2:28 a.m., a sizable Congressional delegation flew down after final votes in order to watch the night turn into day in front of their very eyes. For all the respect and support I have for NASA's satellite missions, those launches simply don't draw those crowds.

NASA's human space flight program is in the midst of a one-in-a-generation transformation brought about by the *Columbia* accident. We are excited by the promise of human exploration beyond low-Earth orbit for the first time in over 35 years. NASA's Constellation Program is developing the Orion crew exploration vehicle and the Ares I and the Ares V launch vehicles. This architecture will give NASA the ability to return Americans to the Moon by 2019 and to establish a scientific outpost so we can gain the expertise to advance human exploration beyond the Moon.

But these changes come with significant costs. Earlier this week, NASA released preliminary estimates of the impact to the human space flight workforce from this transition to a new generation of space flight vehicles. I know this hearing is not intended to focus on transition issues, but I do want to reiterate my concern about the length of this gap and the potential loss of the skilled workforce needed to continue human space flight under the Constellation program.

Mr. Chairman, I understand that you intend to hold a hearing later this year to examine NASA's Shuttle transition planning, and I am very grateful for that proposed hearing. I look forward to working with you on that hearing because it is of utmost importance of Florida's Space Coast and I believe the Nation as well.

In the wake of the *Columbia* accident, the *Columbia* Accident Investigation Board correctly observed that America's human space flight program lacked a strategy and a direction. We have halted that drift. America has established a strategy and an architecture of how to achieve our goals. Now we need stability. We have had enough turmoil and change. If we change the strategy and architecture every few years, we will revert to pre-*Columbia* behavior, and we will have similar results including the very real prospect of being grounded for several years while other nations, especially China, strive for space preeminence.

And I am grateful for the Chairman's remarks about avoiding an unnecessary space race. I intend to go to China the third week of April for the first Global Space Summit. I am adding this off the script. I think it is certainly very aggressive of the Chinese to host the first Global Space Summit but not very surprising, given their announced intentions to be very aggressively pursuing space capabilities.

The *Columbia* Accident Investigation Board correctly noted, "It is the view of the Board that the previous attempts to develop a replacement vehicle for the aging Shuttle represented a failure of national leadership." Since *Columbia,* we collectively, the President, Congress, and the space community, have demonstrated the necessary leadership. The Chairman is right. We haven't funded adequately all of the things we ask NASA to do, but in terms of establishing a vision that is very doable that will lead us into the next age of space exploration, I think that all of us have done our parts in a relatively responsible way.

In over five years, we have come a long way since those terrible dark days in February of 2003. Let us keep that progress in mind as we look forward to the challenges ahead. I look forward from hearing from our witnesses.

Thank you, Mr. Chairman.

[The prepared statement of Mr. Feeney follows:]

PREPARED STATEMENT OF REPRESENTATIVE TOM FEENEY

Thank you, Mr. Chairman, for holding today's important hearing on NASA's Exploration Initiative. I also want to thank our witnesses for appearing. Your perspectives and expertise are immensely valuable as we carry out our oversight responsibilities and prepare legislation to reauthorize NASA.

Human space exploration defines America as the world's preeminent space-faring Nation. Images of Shuttle and Apollo are deeply ingrained in American culture—both our domestic version and the version exported to the rest of the world. Thousands—sometimes hundreds of thousands—of Americans and foreigners come to Florida's Space Coast to witness a Shuttle launch. And for the latest launch held at 2:28 AM, a sizable Congressional delegation flew down after final votes in order to watch night turn into day. For all the respect and support I have for NASA's satellite missions, those launches don't draw these crowds.

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As the *Columbia* Accident Investigation Board correctly noted:

> *It is the view of the Board that the previous attempts to develop a replacement vehicle for the aging Shuttle represented a failure of national leadership.*

Since *Columbia,* we—the President, Congress, and the space community—have demonstrated the needed leadership. In over five years, we have come a long way since those terrible dark days in February 2003. Let's keep that progress in mind as we look forward to the challenges ahead.

Chairman UDALL. Thank you, Mr. Feeney. If there are Members who wish to submit additional opening statements, your statements will be added to the record. Without objection, so ordered.

Let me turn now to our excellent panel of witnesses. I would like to introduce each one of you in turn, and then we will turn to our first witness and he can begin the testimony this morning. First, we do have Dr. Richard Gilbrech who is NASA's Associate Administrator for the Exploration Systems Mission Directorate. Next to him, Ms. Cristina Chaplain who is the Director of Acquisition and Sourcing Management at the Government Accountability Office. Third on the panel, Dr. Noel Hinners who is a former Lockheed-Martin executive and worked on the Apollo program during his tenure at NASA, and finally, we have Dr. Kathryn Thornton who is a veteran of four Shuttle missions and is currently a Professor, Associate Dean for the School of Engineering and Applied Sciences at the University of Virginia. Welcome again to all of you.

As our witnesses should know, spoken testimony is limited to five minutes each after which the Members of the Subcommittee will have five minutes each to ask questions. We will start with Dr. Gilbrech.

STATEMENT OF DR. RICHARD J. GILBRECH, ASSOCIATE ADMINISTRATOR, EXPLORATION SYSTEMS MISSION DIRECTORATE, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)

Dr. GILBRECH. Thank you, Mr. Chairman. Mr. Chairman and Members of the Subcommittee, thank you for the opportunity to appear before you today as NASA's Associate Administrator for the Exploration Systems Mission Directorate. When I joined NASA, I had two dreams. One was to be an astronaut and the other was to be part of the next Moon landing. A heart murmur dashed my first dream but here I am today thrilled to be leading the effort to achieve my second dream.

Much has happened since Americans first landed on the Moon. Today space affects everything we do in more ways than I count here today. The global space economy receives more than $220 billion annually, and NASA is just a small but integral component of that critical global economic engine. Fiscal year 2009, NASA has requested $3.5 billion for our exploration systems programs and projects. This budget request fully reinstates our $500 million commitment to the Commercial Orbital Transportation Services Program. It also demonstrates the President's continued commitment to our nation's leadership in space, especially during a time when there are other competing demands for our nation's financial resources. Budget stability is critical to maintaining the March 2015 initial operating capability for the Orion crew exploration vehicle and the Ares I crew launch vehicles.

Therefore, I ask for Congress' support for this budget request as well as your continued support for NASA's efforts to successfully transition its workforce and infrastructure from Shuttle to Constellation.

NASA's 2009 budget request also continues our efforts to return Americans to the Moon by 2020. On the Moon, astronauts plan to build an outpost to support a long-term human presence there, and in doing so, the Moon will become a proving ground for technologies needed for future human missions to Mars and other destinations. NASA has put together a team of some of its best scientists and engineers to work on the lunar program, and we also are working with 13 other international space agencies in the commercial sector on this important endeavor.

Today, Constellation is making real progress. We are testing real hardware. We have tested landing systems, we have logged thousands of hours in wind tunnels to simulate how the current Ares I vehicle designs perform in flight. By the end of the year, Exploration Systems will launch its first lunar spacecraft from the NASA Kennedy Space Center in Florida. Together, the lunar reconnaissance orbiter and the lunar crater observation and sensing satellite above this spacecraft will help NASA scout for potential lunar landing sites and outposts.

For someone like me who started my career in propulsion technology, this is an exciting time to be leading the team that is building our nation's next generation of human space flight vehicles. Future astronauts will ride to orbit in the Orion crew capsule on top of the Ares I. The Ares I first stage uses a five-segment solid rocket booster derived from the Shuttle's four-segment booster. In the second stage, we use a J–2X engine and will provide the navigation, guidance, control, and propulsion for the rocket's continued assent. Although the J–2X has heritage parts, the J–2X is essentially a new engine because of the significant redesign required for the Ares I propulsion. Having grown up around rocket engine stands, I am very confident that NASA will be successful in developing this new engine to support both the upper stage and the eventual Earth departure stage that will return humans to the Moon.

However, with any new rocket development program, there will be some technical challenges. One of the most recently discovered issues is a problem with thrust oscillation produced by the five-segment first stage booster. Thrust oscillation is caused by vortex shedding inside the solid rocket motor, similar to the wake that follows a fast-moving boat. It is a problem that is common to all solid-rocket motors and one we take seriously. When early analysis indicated there would be high levels of vibration throughout the entire vehicle, NASA assigned our best talent to attack the problem. I am pleased to report today that NASA has made great progress in better understanding the issue and identifying numerous mitigations for thrust oscillation.

Last year the U.S. Government Accountability Office acknowledged that NASA has taken steps toward making sound investment decisions for the Ares I project. Let me assure that NASA fully intends to make sure that all of our projects, not just the Ares I, reach the appropriate level of maturity at each milestone before proceeding further.

Mr. Chairman and Members of the Committee, NASA looks forward to continuing with you on this exciting journey of exploration, a journey that will drive new technologies, enable new economic activity, and engage and inspire our technical and engineering workforce. We do not live in a static world. Other countries will explore the cosmos, whether the United States does or not, and these will be the Earth's great nations in the years and centuries to come. Bold plans and strategies require bold leadership and robust follow-through, and together we can create a legacy for generations to come. I thank you for the opportunity to appear before you today, and I would be pleased to answer any questions you might have.

Chairman UDALL. Thank you, Dr. Gilbrech. Before I recognize Ms. Chaplain, I notice you have some models here, and maybe for the viewers and citizens in attendance you might just take another minute and identify these models to your right for us.

Mr. GILBRECH. Yes, sir, I would be glad to. Show and tell always helps. What we have here on the far end of the table is the Ares I crew exploration crew launch vehicle rocket. We are using the five-segment solid rocket booster that is derived from the Space Shuttle Program as the first stage. The orange section up at the top is the new upper stage that will house the J–2X engine that we are developing, and then the white portion at the very tip is the service module and the Orion crew exploration vehicle, and the little pointy stick at the top is the actual launch abort system which gives us reliability and the ability to save the crew in the event there is a mishap on our way uphill.

The large rocket to the left is the Ares V which uses a lot of the common hardware that we are using with the Ares I. We again have the two, five-segment solid rocket boosters on each side. We are using a core stage which has five RS–68 engines which are the engines that power the Delta IV rockets today. We have the departure stage at the top here which is actually we use the same, common J–2X engine. And then we also have up top the faring that houses the lunar surface access module. We actually have the Orion, a little bit bigger picture here but the idea is the larger rocket will put the lunar surface access module in orbit. The crew will be put up on the Orion capsule. They will mate in Earth orbit rendezvous and then go on their way to the

oon, and we will send all four astronauts down to the lunar surface for seven day sorties in the beginning.

So that is the baseline of the architecture.

Chairman UDALL. But what are the blue arrays that——

Mr. GILBRECH. Those are the solar arrays for powering the Orion capsule since it is much more efficient with the lunar program to use the solar arrays to maximize the energy and minimize the amount of batteries and other types of things we have to have.

[The prepared statement of Dr. Gilbrech follows:]

PREPARED STATEMENT OF RICHARD J. GILBRECH

Mr. Chairman and Members of the Subcommittee, thank you for the opportunity to make my first appearance before you today as the Associate Administrator for the Exploration Systems Mission Directorate (ESMD) to discuss NASA's Exploration Program.

In 2007, ESMD delivered on its promises, and we will continue to do so in 2008. Major development work is underway; contracts are in place, and our future Exploration plan is executable. By the end of 2008, NASA will see its first lunar spacecraft launched from the Agency's Kennedy Space Center (KSC) in Florida. This Lunar Reconnaissance Orbiter (LRO) and the Lunar Crater Observation Sensing Satellite (LCROSS) will help NASA scout for potential lunar landing and outpost sites. Additionally, in 2008, NASA will continue to plan how best to transition any needed Shuttle workforce and infrastructure to the Constellation program.

The FY 2009 budget request of $3.5 billion for ESMD will support continued development of new U.S. human space flight capabilities and will enable sustained and affordable human space exploration after the Space Shuttle is retired at the end of FY 2010. The budget request provides stable funding to allow NASA to continue developing our next-generation U.S. human space flight vehicles while also providing research and developing technologies for the longer-term development of a sustained human Exploration of the Moon and other destinations. Budget stability in FY 2009 is crucial to maintaining a March 2015 Initial Operational Capability (IOC) for the Orion Crew Exploration Vehicle and Ares I Crew Launch Vehicle. There is minimum flexibility through 2010, so Congressional support for the full FY 2009 budget request is critical. In addition, NASA will continue to work with other nations and the commercial sector to coordinate planning, leverage investment, and identify opportunities for specific collaboration on lunar data collection and lunar surface activities.

The FY 2009 budget request continues our national momentum toward returning American astronauts to the Moon by 2020. NASA plans to build an outpost on the Moon to advance U.S. scientific, security, and economic interests as part of a sustained and affordable human and robotic program of solar system Exploration. Astronauts will learn to use resources already on the Moon, preparing for possible future journeys to Mars or other destinations in the solar system. Successful lunar exploration is not just about developing a lander or a habitat. It will require development of a system of Exploration elements, including a transportation system, habitation, rovers, space walking systems, surface power, and communication. NASA has put together a team of some of its best scientists and engineers to work on these projects. We also are working with 13 international partners and the commercial sector to coordinate planning, leverage investment, and identify opportunities for specific collaboration on lunar data collection and lunar surface activities.

Much has happened since Americans first landed on the Moon, but in particular the scope, breadth and importance of space activity has grown significantly. Today, the global space economy exceeds more than $220 billion annually, and that figure is growing rapidly each year. NASA is a small, but integral component of this critical global economic engine. Today, we live in a time when space has become a globally utilized resource and when other nations have the ability to launch humans into space. Today, the skies are filled with satellites that impact the lives of billions of people on planet Earth. Today, American astronauts are living in space with international colleagues aboard the International Space Station (ISS), and scientists worldwide are studying our solar system via robotic missions. Simply put, space affects everything we do.

Thanks to the support of the President and Congress, our nation once again has a vision for the future that addresses space Exploration on all fronts. It is therefore only fitting that we have begun on an adventure to return Americans to the Moon as part of that broader policy and vision. This adventure will drive us toward new technologies; will enable a new area of economic activity; will strengthen our national security; will engage our technical and engineering workforce; will provide an opportunity to collaborate on important missions with our international partners; and, will inspire a new generation of scientists and engineers to participate in America's space program. NASA's Exploration program will also ensure that our nation's space program continues to organize and inspire the best of our energies and skills for generations to come.

NASA is committed to carrying out our nation's civil space program, and we pledge to keep the Congress fully informed about our efforts and achievements. As requested in the invitation to testify today, the remainder of my testimony outlines NASA's progress, and some of the Agency's challenges, in implementing the Orion and Ares projects. My testimony also addresses NASA's evolving lunar architecture, which will return Americans to the Moon by 2020 in preparation for human Exploration of Mars and other destinations.

Constellation Program Status

The FY 2009 budget request for Constellation Systems is approximately $3.0 billion. The Constellation program includes funding for the Orion and Ares projects, as well as for ground operations, mission operations, and extra vehicular activity projects and a dedicated in-house effort for systems engineering and integration. NASA recognizes that challenges lay ahead for the Agency, and we are making progress in managing these challenges. Our greatest challenge is safely flying the Space Shuttle to complete assembly of the ISS prior to retiring the Shuttle in 2010, while at the same time, developing new U.S. human space flight capabilities of the Constellation program and successfully transitioning our workforce between Shuttle and Constellation activities. Full funding of NASA's FY 2009 budget request for Constellation is needed so that we can continue successful transition between the Shuttle and the Orion and Ares I. The FY 2009 budget request maintains Orion IOC in March 2015 at a 65 percent confidence level and full operational capability (FOC) in FY 2016, though NASA is striving to bring this new vehicle online sooner.

The FY 2009 budget request for Constellation will support a total of three uncrewed test flights prior to IOC in FY 2015. The IOC is defined as the first crewed flight of Orion to the ISS, enabling fight test astronauts to fly the Orion on its maiden voyage. Following IOC, there will be one additional crewed test flight of Ares I and Orion to the ISS before NASA declares FOC. The FOC milestone is defined as the date when Orion transports crew to the ISS; remains at the ISS for up to 180 days; and then safely returns the crew to Earth.

NASA has planned and paced the multi-decade Constellation program to live within its means, while carefully identifying and mitigating the threats to mission success. Within the Constellation program, NASA is making important decisions to stay within budget and on schedule by striving for the lowest life-cycle costs possible. NASA has established an initial plan for Constellation's designs and integrated flight tests to ensure that the Agency adequately tests systems prior to their operational use and allows appropriate time to implement critical lessons learned from these tests.

NASA's Constellation program has moved beyond being just a mere concept on paper; we are making real progress. We have tested hardware; we have tested landing systems; and we have logged thousands of hours in wind tunnels. So far, the Ares I project has conducted more than 4,000 hours of wind tunnel testing on subscale models of the Ares I to simulate how the current vehicle design performs in flight. These tests support development of the J–2X engine for the Ares I and the Earth Departure Stage of the Ares V. By December 2007, all major elements of the Orion and Ares vehicles were placed under contract. This year, Constellation will be busy with hardware activities which include fabrication of the First Stage Development Motors 1 and 2 for Ares I; complete construction of the Upper Stage Common Bulkhead Demonstration article and also deliver the first Ares I–X demonstration test flight hardware to KSC in October 2008. Orion will be just as busy, culminating the year with a test of its launch abort system at the U.S. Army's White Sands Missile Range (WSRM) in New Mexico.

NASA has a dedicated group of civil servants and contractors who work together to check and crosscheck the multiple variables that go into designing and eventually operating these future Exploration vehicles. Constellation also has an integrated schedule and we are meeting our early milestones. In 2007, Constellation completed a "Season of System Requirements Reviews" for the program and its projects. Design reviews are essential to good engineering practice. The year culminated with an Orion Point of Departure (POD) design and a green light to move forward to the Preliminary Design Review (PDR). An Integrated Stack Technical Interchange Meeting also was a great success with all top issues being resolved. Thus, the Constellation program was able to strike a technical baseline from which integrated assessments can be formed. The program closed the architecture for going back to ISS; has identified the areas necessary to do the same for lunar; and now has a clearer understanding of its growth path toward that goal. Constellation also has the green light to move forward in developing systems for a lunar capable vehicle that meets our budgets and schedule needs. Agency leadership has embraced the results of this season of reviews and has approved the Constellation program to move forward to PDR for both Orion and Ares I by this fall.

For background, a PDR is a crucial milestone because it is the first major review of the detailed design and is normally held prior to the preparation of formal design drawings. During a PDR, the program verifies that the preliminary design meets all requirements within acceptable risk limits and within the cost and schedule constraints. The completion of the PDR and the closure of any actions generated by the review become the basis for the start of the detailed drafting and design effort and the purchase of parts, materials, and equipment needed.

Currently, NASA has civil servants and contractors on board for the Constellation program serving at all ten field Centers. Last fall, the Agency assigned new leadership roles and responsibilities for Exploration and Science missions to NASA's ten field Centers in order to help restore the core technical capabilities across the Agency as we transition from the Space Shuttle to new capabilities. This action included assigning preliminary work assignments covering elements of the Altair human lunar lander and lunar surface operations, as well as the Ares V and Earth Departure Stage necessary for lunar Exploration. This year, NASA will continue efforts to define the specific work the field Centers will perform in order to enable astronauts to again explore the Moon, while paving the way for human Exploration of Mars and other destinations. It is also important to note that NASA's Constellation program involves industry partners from more than 20 states across the country, which makes Constellation a truly Nationwide effort.

In addition, NASA is making infrastructure improvements at many of our Centers including:

- Modifications to the Space Power Facility (SPF) at Glenn Research Center's Plum Brook Station (Ohio) in support of Orion environmental testing, enabling the SPF to perform vibration and vibro-acoustic testing;
- Construction of a new high-altitude test stand at Stennis Space Center (SSC) in Mississippi for testing the J–2X Upper State engine under simulated high-altitude conditions;
- Construction of Orion abort system testing facilities at WSMR;
- Major refurbishment of the Operations and Check-out Building at KSC in support of Orion final assembly and test;
- Major refurbishment of building 29 at Johnson Space Center (JSC) in Texas to support a Constellation Avionics Integration Lab in support of Orion; and,
- Minor and major modifications to Arc Jet Heaters located at JSC and Ames Research Center in California in support of Orion heat shield development and qualification.

Status of the Orion Crew Exploration Vehicle

By 2020, America will send a new generation of explorers to the Moon aboard the Orion crew module, thereby enabling a sustained human presence beyond low-Earth Orbit (LEO). With its IOC of March 2015, Orion is a critical capability for the Nation to support Exploration and to ensure U.S. access by American astronauts to all regions of LEO and the Moon. The Orion also opens the door to Mars and other destinations.

NASA is continuing the design process for the Orion and is pleased with the progress made so far. The current design configuration establishes a robust vehicle and meets the weight requirements, including meeting the more demanding lunar configurations. Orion's design borrows its shape from the capsules of the past, but takes advantage of 21st century technology in computers, electronics, life support, propulsion, and heat protection systems. Orion will carry up to four crew members on lunar missions and up to six crew members to and from the ISS. By 2020, the new capsule will be able to rendezvous with a lunar landing module, which will carry astronauts to the Moon's surface. Orion also will be the vehicle that returns our astronauts safely to Earth.

During 2007, the Orion project tested numerous options for landing systems, including air bag systems of varying configurations, and the project began fabrication of a flight test article for Pad Abort Test-1. Both the Orion and Ares projects also conducted numerous recovery parachute drop tests in Yuma, Arizona to better understand the reefing performance of the drogue, pilot and main chutes. Last year also included a season of design reviews for the Orion project. After completing a System Definition Review (SDR) in August, the Orion team realized that the Orion configuration was too heavy, so NASA began an effort to establish a POD configuration for the Orion spacecraft that would meet requirements for mass, power and cost. In November 2007, NASA senior leaders, including Administrator Michael Griffin, approved the POD and approved Orion to move forward into the PDR design cycle, which is scheduled to conclude this fall.

As approved in November, the POD configuration:

- Establishes a robust vehicle;
- Meets weight requirements for lunar and ISS missions; and
- Meets the more demanding lunar configuration with 2,000 lb of Manager's Reserve (MR) and 15 percent average Weight Growth Allowance; This MR covers the 90th percentile of mass threats and opportunities identified.

Between now and the conclusion of PDR this fall, NASA will continue to work these issues:

- Crew support for safety;
- Ensuring the vehicle adequately supports the crew in the event of contingency landings when the crew may have to spend an extended period of time in the vehicle prior to recovery by ground support teams;
- Assessing landing scenarios, leading to a final decision about whether Orion will land on land or water during nominal landings;
- Assessing mass threats and opportunities against the Orion PDR POD configuration; and
- Understanding the vulnerabilities of the POD vehicle and understand the Loss of Crew and Loss of Mission probabilities.

Another integral part of the Orion project is a Launch Abort System (LAS), which 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 the 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 rocket and positioning the Orion for a safe landing. The planned LAS implementation uses a solid rocket motor that is positioned on a tower atop the crew module that will pull the Orion and its crew to safety. NASA plans a series of tests to characterize the LAS. Pad Abort (PA)–1 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. This test is scheduled for December 2008 at WSMR. The Orion crew module test article was shipped to Dryden Flight Research Center, California, on March 27 for outfitting. It will then be shipped to White Sands for integration with the launch vehicle and LAS for the December 2008 PA–1 test.

Status of the Ares I Crew Launch Vehicle

Ares I is an in-line, two-stage rocket that will carry Orion to LEO and will becomes NASA's primary vehicle for human exploration in the next decade. Ares I will be able to lift more than 25 metric tons (55,600 pounds) to LEO. Its First Stage will use a single five-segment solid rocket booster—a derivative of the Space Shuttle's solid rocket booster, which also will be a critical element of the Ares V heavy lift launch vehicle. The Ares V will consist of two five segment strap-on boosters, which will enable the Ares V to carry up to 65 metric tons (143,299 pounds) of payload to trans-lunar injection orbit or 135 metric tons (297,624 pounds) to LEO. The Ares V represents a capability far beyond that of today's global launch systems, opening the door to exploration and to a range of national and scientific applications in all regions of space. The Second Stage of the Ares I, also known as the Upper Stage, will provide the navigation, guidance, control and propulsion required for the Second Stage of the rocket's ascent. It will consist of a J–2X engine, a fuel tank for liquid oxygen and liquid hydrogen propellants and associated avionics. Like the solid rocket booster, the J–2X will contribute to our plans for human lunar exploration by powering the Earth Departure Stage (the vehicle carrying the Orion and a human lunar lander) to the Moon.

The J–2X is an evolved version of two historic predecessors: the powerful J–2 engine that propelled the Apollo-era Saturn I–B and Saturn V rockets, and the J–2S, a simplified version of the J–2 that was developed and tested in the early 1970s. By utilizing the J–2X, NASA eliminates the need to develop, modify, and certify an expendable Space Shuttle engine for the Ares I. NASA expects the J–2X to be less expensive and easier to manufacture than the Space Shuttle main engine. Changing from the four-segment First Stage solid rocket motor to the five-stage segment for the Ares I also represents a significant and direct down payment on the Ares V, enabling an earlier delivery date for Ares V.

Although the J–2X is based on the J–2 and J–2S engines used on the Saturn V, it also leverages knowledge from the X–33 and RS–68. NASA also is planning significant upgrades to the engine, which essentially makes the J–2X a new engine development program. Therefore, NASA has taken steps to mitigate J–2X risks by increasing the amount of component-level testing; procuring additional development hardware; and working to make a third test stand available to the contractor earlier than originally planned. On August 23, 2007, NASA broke ground on a new rocket engine test stand at Stennis Space Center in Mississippi. The test stand will provide altitude testing for the J–2X engine and will allow engineers to simulate flight conditions at different altitudes. Testing on the A–3 stand is scheduled to begin in late 2010.

Last year, the Ares project office conducted a season of SDRs for its major elements: First Stage, Upper State and Upper Stage engine. These activities concluded with the integrated Ares I SDR in October 2007. In support of Orion and Ares I SDRs, a series of integrated vehicle analyses were conducted to characterize performance of the Orion/Ares I stack. During these reviews, NASA discussed a thrust oscillation issue during First Stage operation. Thrust oscillation is not an uncommon risk in solid rocket motors because thrust oscillation or resonant burning is a characteristic of all solid rocket motors, like the First Stage of the Ares I launch vehicle. It is caused by vortex shedding inside the solid rocket motor, similar to the wake that follows a fast moving boat. When the vortex shedding coincides with the acoustic modes of the motor combustion chamber, pressure oscillations generate longitudinal forces that may impact the loads experienced by the Ares I during flight, and may exceed allowable loads on various portions of the vehicle and allowable forces on the astronaut crew.

In November 2007, NASA chartered the Thrust Oscillation Focus Team to precisely define the frequency spectrum and oscillation amplitudes that the five segment motor is expected to produce. These analyses are being accomplished using a combination of available ground test motor data as well as early Shuttle solid rocket motor flight data. Efforts are underway to update the existing data set by adding instrumentation on several upcoming Shuttle flights. In parallel, the team is evaluating vehicle structural assessments in order to provide additional vibration isolation to critical launch vehicle systems and uncouple the vehicle's natural frequency from motor induced loads. Since upper stage elements and the command/service module are not yet fully designed, this is an excellent time to factor in thrust oscillation load mitigation should that be required. The team's analysis has already led to several mitigation strategies, including the removal of a significant amount of conservatism from within existing models, correlating to significantly lower loads by a factor of almost two. Additionally the team was able to remove the first longitudinal mode as an issue—the remaining effects are now in a narrow, manageable region in the 12Hz frequency range. NASA will conduct additional analysis coupled with upcoming flight test on the Shuttle (STS 125, planned for August 2008) and Ares I–X (planned for April 2009) to better characterize this phenomenon, which may further reduce loads. In summary, NASA is confident in its ability to mitigate the risks associated with thrust oscillation, and we will keep the Congress and this subcommittee informed of our progress.

Last year, the U.S. Government Accountability Office (GAO) acknowledged that NASA has taken steps toward making sound investment decisions for the Ares I launch vehicle. GAO reported that NASA is relying on established technology to support the project and is adopting an acquisition strategy that emphasizes attaining knowledge on cost, schedule and technical and development feasibility before commitments are made to long-term investments. The GAO also rightly identified many of the challenges that still remain for the Ares I project—requirements complexities, design details, and a challenging schedule are particularly highlighted, among others. NASA has made a great deal of progress to date on Ares I; we have accomplished much in a short period. However, I am well aware that there is still much to be done. The GAO recommends that NASA develop firm requirements, a preliminary design, and realistic cost estimates in time for the Ares I PDR late this summer. This is exactly our intent—to make sure that all of our projects, not just Ares I, reach the appropriate level of maturity at each milestone before they proceed further. I have every confidence that our team will build on our recent progress, overcome the challenges immediately before us, and successfully reach our next goal.

In December 2008, NASA will complete the integrated stack sync point for Orion and Ares I, which is a key milestone in the development progress of these projects. The integrated stack sync point will demonstrate that Ares I and Orion preliminary designs, as well as the integrated stack analyses, have met all system requirements within acceptable risk and within the cost and schedule constraints. The sync point establishes the basis for proceeding to the Constellation Program-level PDR. The integrated sync point also will show that the correct design options have been selected; interfaces have been identified; and verification methods have been described. The Orion and Ares I project offices are currently finalizing data products required to meet their individual project-level PDRs. Should key information not be available by December 2008, the program will evaluate delinquent data product status and provide a strategy to ensure products are available to support the program PDR. The program office would then apply appropriate resources to mitigate delinquent product risks.

Let me re-emphasize that the Constellation program has moved beyond just drawings and into real hardware fabrication and testing. For example, beginning in late 2006 and continuing into 2008, sub-scale main injector hardware underwent hot-fire testing to support development of the Upper Stage engine for NASA's Ares I crew launch vehicle and Earth Departure Stage of the Ares V cargo launch vehicle. The hot-fire tests are part of efforts to investigate design options for, and maximize performance of, the J–2X Upper Stage engine. NASA engineers also have conducted more than 4,000 hours of wind tunnel testing on sub-scale models of the Ares I to simulate how the current vehicle design performs in flight. These tests will lay the ground work for NASA's first scheduled demonstration test flight for Ares I, called Ares I–X, scheduled for April 2009. That is just a mere 12 months from now.

Ares I–X will be the first demonstration flight of the technologies for and components of the new U.S. Exploration launch vehicle system. Important technical highlights of the Ares I–X test flight are: demonstration of First Stage separation sequencing; an assessment of First Stage atmospheric reentry characteristics; an assessment of vehicle roll torque while in flight; and a demonstration of assembly and recovery activities for a new launch vehicle at KSC. NASA recognizes that there are technical challenges related to parachute testing, modal testing and loads and environments, and we are working to mitigate those risks.

The Commercial Crew and Cargo Program

In FY 2009, NASA is requesting $173 million for the Commercial Crew and Cargo Program and its associated Commercial Orbital Transportation Services (COTS) projects. Full funding is essential to maintaining NASA's promised $500 million investment in this program to spur the development of U.S. commercial space transportation services to and from low-Earth orbit (LEO) while also providing substantial savings to the taxpayer compared to NASA Government-owned and operated capabilities.

The objectives of this program are to: 1) implement U.S. Space Exploration policy with an investment to stimulate commercial enterprises in space; 2) spur the development of U.S. commercial space transportation services to and from LEO; and, 3) enhance U.S. access to LEO and the ISS while also providing substantial savings to the taxpayer compared to NASA Government-owned and operated capabilities. The availability of safe, reliable and economical service to LEO will help NASA achieve the Nation's goals of retiring the Space Shuttle, servicing the ISS (designated as a National Lab pursuant to the *NASA Authorization Act of 2005,* 109–155), and building a new transportation system that expands our nation's sphere of economic and scientific influence on the Moon and beyond.

COTS is envisioned for execution in two phases. Phase 1 is a period of development and demonstration by private industry, in coordination with NASA via funded and unfunded Space Act Agreements (SAAs), of various space transportation capabilities to and from low-Earth orbit determined to be most desirable for the government and other customers. Once a capability is demonstrated, NASA will enter into the second phase, which will be a competitive procurement of orbital transportation services to supply the ISS. A commercial services resupply contract will be managed by NASA's Space Operations Mission Directorate. A draft Request for Proposals for this contract was issued on February 28, 2008, and a final RFP is on track to be issued later this month.

As part of Phase I, NASA has negotiated funded SAAs with two partners. Each SAA has individualized milestones and objective criteria that spell out in detail a schedule of performance milestones that each participant is expected to achieve along with a fixed payment to be made upon completion. These milestones culminate in a flight demonstration where the participant's vehicle will launch, rendezvous and berth with the ISS, and in the case of one partner's demonstration, return safely to Earth. The funded partners are paid a pre-negotiated fixed amount only if they successfully complete a milestone. If they do not complete the milestone to NASA's satisfaction, they are not paid. These milestones can be technical (for example, a successful design review or hardware test) or financial (i.e., raising a certain amount of private funding).

Altogether, NASA is providing about $500 million over five years to stimulate the commercial space transportation market to help develop safe, reliable and cost-effective access to and from LEO:

- In August 2006, NASA signed a funded SAA with Space Exploration Technologies Corp. of El Segundo, Calif., also known as SpaceX. The company is scheduled to receive $278 million to supplement its privately funded efforts and is planning to conduct a demonstration flight to the ISS in March 2010. In early February, SpaceX formally notified NASA that it was projecting a six to nine month delay in the launch of the Falcon 9 launch vehicle and Dragon spacecraft demonstration missions. On Feb. 28, 2008, NASA executed an amendment to the SpaceX SAA, renegotiating milestones to align the current development and demonstration schedule with ISS integration activities. Also, several milestones were added and others modified to allow additional insight and clarification of objective measures of progress of the demonstration program. SpaceX has met all milestones to date and continues to make excellent progress in the development of its launch vehicle and cargo capsule. The total NASA investment in this agreement of up to $278 million remains unchanged, although individual performance payments for some milestones have been adjusted. SpaceX has received a total of $139 million for successfully completing the first eight milestones.
- On Feb. 19, 2008, NASA announced the selection of Orbital Sciences Corporation of Dulles, Va., for a second funded SAA to replace the Space Act agreement that NASA terminated with Rocketplane-Kistler (RpK) in October 2007 for RpK's failure to perform under the terms of the agreement. Orbital will receive approximately $170 million to supplement its privately funded efforts and is planning to conduct a demonstration flight to ISS in December 2010. The funds made available for Orbital's award were funds not previously used by RpK.
- NASA also has entered into unfunded SAAs with five other companies—Constellation Services International, PlanetSpace, SpaceDev, SpaceHab, and Transformational Space Corp (t/Space).

Lunar Implementation

A human space flight program with no plan to send people beyond the orbiting ISS certainly is not in our nation's best economic or strategic interest. The *Columbia* Accident Investigation Board (CAIB), which examined the 2003 loss of the Shuttle and its crew, acknowledged that for the foreseeable future, space travel is going to be expensive, difficult and dangerous, but emphasized that U.S. human space flight is not only strategic, but also what makes us a great nation. The report noted that not developing a replacement vehicle for the Space Shuttle demonstrated a failure of National leadership and also declared that if we are going to send humans into space, the goals ought to be worthy of the cost, the risk and the difficulty.

President Bush responded to the CAIB report. The Administration looked at where we had been in space and concluded that we needed to do more, to go further. The result was the *Vision for Space Exploration,* announced nearly four years ago, which commits the United States to using the Shuttle to complete the ISS, then retiring the Shuttle and building a new generation of spacecraft to venture out into the solar system. Congress ratified that position with an overwhelming bipartisan majority, making the Vision the law of the land in 2005 upon the adoption of the *NASA Authorization Act of 2005.* Congress specifically directed NASA "to establish a program to develop a sustained human presence on the Moon, including a robust precursor program to promote exploration, science, commerce and U.S. preeminence in space, and as a stepping stone to future exploration of Mars and other destinations."

As NASA Administrator Michael Griffin eloquently outlined in a 2007 speech, NASA is moving forward with a new focus for its human space program—to go out beyond LEO for purposes of human Exploration and scientific discovery. If humans are indeed going to travel to Mars, if we're going to go beyond, we have to learn how to live on other planetary surfaces, to use what we find there and bend it to our will. If we are to maintain our global leadership as a space-faring nation, we have to survive in other forbidding, faraway places across the vastness of space. The Moon is a crucially important stepping stone along that path; it is an alien world, yet one that is only a three-day journey from Earth.

In 2006, NASA and 12 international partners established the Global Exploration Strategy (GES) team to identify primary themes and objectives for lunar Exploration. These objectives were grouped into six themes: 1) human civilization; 2) scientific knowledge; 3) Exploration preparation; 4) global partnerships; 5) economic expansion; and 6) public outreach. These themes and objectives serve as the foundation for the development of the lunar architecture currently under development. More specifically, NASA identified several guiding principles for the lunar architecture which include:

- Human lunar missions will be used to build an outpost initially at a polar site;
- Preserve the option for an outpost at other lunar locations;
- Preserve the ability to fly human sorties and cargo missions with the human lander;
- Initial power architecture will be solar with the potential for augmentation with nuclear power later;
- The United States will build the transportation infrastructure, initial communication and navigation infrastructure, and initial surface extra vehicular activity (EVA) capability (i.e., Moon walk);
- Open Architecture: NASA will welcome parallel development and development of lunar surface infrastructure by international and commercial interests;
- Early exploration: Reduced assembly through pre-integrated habitats;
- Modular mobile habitation:
  - Facilitates "super sortie" mobility for 100's km distances from the outpost
  - Facilitates greater lunar access to capture exploration and science objectives beyond LAT1 results; and,
- Early small pressurized rover
  - Augments EVA operations by allowing astronauts to explore in shirt sleeve environment using EVA judiciously.

Utilizing these guiding principles, NASA is conducting early concept studies for an outpost on the Moon. An Agency-wide team has been hard at work, looking at concepts for habitation, rovers and space suits. When NASA returns Americans to the Moon in 2020, astronauts will set up a lunar outpost, possibly at the south pole, possibly at a site called the Shackleton Crater, where they will conduct scientific research, as well as test technologies and techniques for Exploration of Mars and other destinations. The architecture concept utilizes a building block approach to maintain the maximum amount of flexibility should NASA want to be able to land at varying locations on the lunar surface.

Data from the LRO and LCROSS missions will enable future outpost site selection and new information about resources within the permanently shadowed craters at the lunar poles. The LRO/LCROSS missions also represent NASA's first steps in returning to the Moon. More specifically, the LRO will develop a highly detailed, topographic map of the lunar surface to help prepare the way for humans to return in the next decade. Information from the robotic spacecraft will be used to select safe landing sites for the next generation of lunar explorers. LRO also will provide valuable information about the environment and resource availability on the lunar surface. While the Apollo missions focused on gaining Science from the area around the Moon's equator, the LRO will circle the poles. It will spend at least one year in low, polar orbit, with instruments working simultaneously to collect detailed information about the lunar environment. The mission objective is to collect the highest resolution and most comprehensive data set ever returned from the Moon. The LRO, which is being built at NASA's Goddard Space Flight Center in Maryland, will carry six instruments and a technology demonstration payload. The LRO is scheduled to be launched atop an Atlas 5 rocket from KSC by the end of the year. The same rocket also is scheduled to loft the LCROSS spacecraft, which is designed to detect water in a permanently-shadowed crater at the lunar south pole.

In response to Congressional direction contained in the Explanatory Statement accompanying the *Consolidated Appropriations Act,* 2008 (P.L. 110–161), NASA will fund a robotic lander project managed by the Agency's Marshall Space Flight Center in Alabama as a pathfinder for an anticipated network of small science robotic landers based on requirements for NASA's expanded lunar Science program. The first robotic lander mission is planned to fly in 2013–2014. NASA's Exploration and Science Mission Directorates will continue to work together, as they do on numerous projects, to combine resources to ensure that the goals of the Science robotic lander are achieved.

Work on the human lunar lander also is progressing. On March 17, 2008, NASA's Constellation Program awarded a 210-day study contract to five space-related companies to independently evaluate NASA's in-house design concept for the lunar lander that will deliver four astronauts to the surface of the Moon by 2020. The awards total approximately $1.5 million, with a maximum individual award of $350,000. The study recommendations will be used to increase the technical maturity of the existing design, in preparation for the development of vehicle requirements. These studies will provide valuable input for developing a sound set of requirement for the Altair lunar lander.

Once astronauts set foot on the Moon, they will need some place to live. NASA had been considering integrated habitation units emplaced by a cargo lander. The team is also discussing the possibility of a mobile habitat module that would allow one module of the outpost to relocate to other lunar destinations as mission needs dictate. The outpost approach provides the flexibility needed to incorporate international and commercial contributions to the lunar outpost architecture. International collaboration can help achieve global exploration objectives faster than if NASA attempted to deploy the entire lunar Exploration architectural elements alone.

As part of the lunar architecture, NASA is considering utilizing small, pressurized rovers that would be key to productive operations on the Moon's surface. Engineers envision rovers that could travel in pairs—two astronauts in each rover—and could be driven nearly 100 kilometers away from the outpost to conduct Science and other activities. Astronauts inside the rovers wouldn't need special clothing because the pressurized rovers would have what's called a "shirt-sleeve environment." It is envisioned that the spacesuits would be attached to the exterior of the rover. Astronauts could crawl directly from the rovers into the suits to begin a Moon walk.

NASA has been engaged with its international partners since 2005, particularly following the GES team's establishment in 2006. Since then, NASA has worked hard to effectively communicate our plans to our international partners about our efforts to develop the transportation systems required to travel between the Earth surface and the lunar surface. We also have clearly communicated our desire and interest in open collaboration on outpost elements. After several months of collaboration, NASA and 12 other international agencies developed a joint document titled, *The Global Exploration Strategy: The Framework for Coordination.* The *Framework Document,* as it is commonly referred to, identifies the common themes that all nations can identify with in the course of exploring space and establishes some basic principles for cooperation. During future discussions, NASA will work with our partners to define standard interface information to minimize to the greatest extent possible integration costs. We have recently completed discussions with our international partners on lunar communication standards.

Additionally, NASA is already working with both the Japanese and Indian space agencies on two projects that will help better inform our lunar efforts. Last September, the Japanese Aerospace Exploration Agency launched its SELENE/Kaguya mission, which will provide NASA with altimetry data to help improve our targeting for the LCROSS mission. NASA also is planning to include two instruments this summer on the Chandrayaan-1 mission, which the Indian Space Research Organization plans to launch this summer. These instruments will help us better understand the formation and evolution of the Moon, for the needs of both NASA's ESMD and SMD programs and projects. Using radar, we will also be able to look into the permanently shadowed craters at the poles of the Moon, and since the LCROSS impactor will be sent to one of these craters, it is important for us to have an initial idea of the surface characteristics of the possible target sites for the LCROSS impact.

Advanced Capabilities

The Agency's FY 2009 budget request also provides $452 million for activities in ESMD's Advanced Capabilities theme, which seeks ways to reduce the risks for human explorers of the Moon and beyond by conducting research and developing and maturing new technologies. This year, NASA's Human Research Program will focus on the highest risks to crew health and performance during exploration missions. We also will develop and validate technologies that serve to reduce medical risks associated with human space flight. For example, NASA will continue its work to understand the effect of space radiation on humans and to develop effective mitigation strategies. Next year, the Advanced Capabilities Exploration Technology Development program will conduct a range of activities, including testing prototype ablative heat shield materials; throttleable liquid oxygen/liquid hydrogen engines suitable for a human lunar lander; and lightweight life support systems for Orion. The program also will deploy and test advanced environmental monitoring systems on the ISS to advance the safety of crew members, and will continue to test in-situ resource utilization technologies as well as life support and cryogenic fluid management.

For ESMD, the Advanced Capabilities Division has the lead for research on-board the ISS. During 2008, NASA will continue to conduct research on-board ISS that will include experiments on human adaptation to microgravity, as well as biological and microgravity experiments. It is important to note that the ISS will support astronaut return to the Moon by providing a reduced gravity environment for studying human health effects and effective countermeasures. While the Moon does have gravity, it is unknown if its small fractional gravity will be enough so that normal physiological function can occur over longer durations. Information from ISS will provide a basis for the types of countermeasures that we will need to develop for long-range lunar habitation and the eventual long-transit journeys to Mars and beyond. NASA will adjust these countermeasures as we get additional data from initial lunar human explorers. In the meantime, we will use ground-based analogs to help us gain additional insight into fractional gravity and its effect on astronaut explorers.

NASA is balancing its portfolio to meet the requirements of the NASA Authorization Act of 2005, pertaining to non-Exploration research. In the FY 2009 budget, NASA budgeted $138 million for Exploration-related research and $30 million for non-Exploration research, resulting in 18 percent of the ISS research budget being spent on non-Exploration research.

NASA is developing long-range plans to utilize the ISS and free flyers beyond 2010. Non-Exploration payloads for ISS will use existing or soon to be delivered science facilities and racks. NASA is aggressively working to utilize the ISS for both Exploration and non-Exploration payloads. During 2007, NASA participated with a Russian biomedical institute to investigate fundamental biological processes in a number of living organisms through experiments using a Russian free flying spacecraft, the Foton M3. NASA continued development work on a nanosat that will investigate the effectiveness of anti-fungal agents on fungi in microgravity. That mission is scheduled to launch on the TacSat 3 mission this fall. On the ISS, fundamental physical science payloads, such as the Binary Colloidal Alloy Test and the Capillary Flow Experiment will provide fundamental information and validate hypotheses concerning the behavior of physical systems in microgravity.

NASA continues to integrate Science and Exploration initiatives on several fronts. For example, the two mission directorates are collaborating on plans for Radioisotope Power Systems. Additionally, ESMD and SMD are cooperating on the LRO. The LRO has been designed, developed, and will be launched and operated by ESMD for the first year in order to develop a topographic map of the Moon for the identification of lunar landing sites, and will later be transitioned to SMD for additional Scientific activities. In addition, ESMD and SMD have established an Outpost Science and Exploration Working Group to coordinate lunar exploration activities between the two directorates. One of the group's key objectives is to jointly identify Science requirements that could affect the Exploration architecture prior to lunar systems PDRs. Architecture considerations driven by Science community recommendations could include requirements such as telerobotic capabilities from both the outpost or ground stations and mobility greater than 100 km from the outpost.

Seeking Synergies Between Constellation and Lunar Architectures

In your invitation today, you asked me to address how NASA plans to accommodate its goals for the Constellation and lunar programs while also dealing with constrained budgets. As stated before, full funding of NASA's FY 2009 budget request for Constellation is needed so that NASA can continue successful transition between the Shuttle and the Orion and Ares I. The FY 2009 budget request maintains Orion IOC in March 2015 and FOC in FY 2016 and provides stable funding in the out years. NASA stands behind the President's budget and the Exploration roadmap that it supports. In doing so, NASA pledges to consistently look for ways to optimize performance, decrease costs, increase reliability and sustain safety, while also maintaining alignment with the goals and objectives outlined by the President and the Congress for this multi-decadal Exploration endeavor.

To mitigate some risk, NASA is consistently looking for synergies between the Constellation and lunar architectures. For example, NASA has defined a transportation architecture that maximizes subsystem commonality between crew access to ISS and the lunar program. Benefits of this common design approach include a comprehensive decrease in Design, Development Test & Evaluation (DDT&E) nonrecurring expenses, and lower recurring vehicle manufacturing, logistics, processing, and maintenance costs realized through commonality of tooling, ground support equipment, launch pad interfaces, and mission scenarios. Developing common Ares I and Ares V propulsion systems means that manufacturing facilities, ground support systems, and launch site infrastructure modifications and improvements can be jointly applicable and leveraged to reducing both recurring and nonrecurring operations costs throughout the life cycle of each system.

NASA also plans to reap benefits and efficiencies by partnering with the Shuttle program and by deciding to utilize a five-segment reusable solid rocket booster (RSRB) for the Ares I First Stage. Specifically, developing the five-segment RSRB for the Ares I and later migrating it to the Ares V Core Stage propulsion system will result in significant out-year savings on DDT&E costs. Aside from cost savings associated with this approach, this approach may potentially enable earlier Ares V availability, given that the risks associated with developing the five-segment RSRB would have been resolved before embarking on other core stage propulsion element work.

Conclusion

Throughout history, the great nations have been the ones at the forefront of the frontiers of their time. Britain became great in the 17th century through its exploration and mastery of the seas. America's greatness in the 20th century stemmed largely from its mastery of the air. In this new century, those who effectively utilize space will enjoy added prosperity and security and will hold a substantial advantage over those who do not. In order to increase knowledge, discovery, economic prosperity, and to enhance National security, the United States must have robust, effective, and efficient space capabilities. We do not live in a static world—other countries will explore the cosmos, whether the United States does or not, and those will be Earth's great nations in the years and centuries to come. Bold plans and strategies require bold leadership and robust follow-through. Together we can create a bold legacy for generations to come.

Today I have highlighted for you some of NASA's progress in developing the Constellation and lunar architectures—and some of the challenges that lay ahead. NASA knows it has a lot of hard work, but we are continuing to make steady progress. In the span of a few short years, we have already taken long strides in the formulation of strategies and programs that will take us back to the Moon and on to Mars and other destinations in our solar system. Indeed, a generation from now, astronauts on the Moon and Mars will be flying in and living aboard hardware America is funding and designing today, and will be building in the near future. This is a heady legacy to which we can aspire as we develop the next U.S. human space exploration vehicles. The foundation of this legacy will include work we plan to carry out in FY 2009.

I want to stress the criticality to the Nation of meeting our goal of successfully transitioning from the retirement of the Space Shuttle to the operation of Orion and Ares I. NASA's Exploration Systems and Space Operations Mission Directorates are continuing to work closely to determine how best to transition our valuable infrastructure and workforce to the Constellation program in support of our Exploration plans. Our transition plan continues to be refined which will closely align Shuttle and Constellation activities and outline clear milestones to achieve the synergies required. I would like to ask this Subcommittee for your continued support as we effectively transition key elements of our Space Shuttle workforce, infrastructure and equipment for our nation's Exploration objectives. Our efforts are complex and intertwined between ESMD and SOMD, and that is why sustained purpose, direction and budget stability are particularly important.

NASA is at the beginning of a new adventure. It is an adventure that presents challenges that are appropriate for the talents and resources of our nation; fitting to the profound impact of space activities on a global scale; and respectful of the sacrifices that have been made in the continued pursuit of space Exploration. For my part, I look forward to the challenge of Exploration and to working with you and an energized NASA workforce to accomplish our goals.

Mr. Chairman, with your support and that of this subcommittee, we are making the right strategic choices for our nation's space program. Again, thank you for the opportunity to appear before you today. I would be pleased to respond to any questions that you may have.

BIOGRAPHY FOR RICHARD J. GILBRECH

Richard J. Gilbrech is Associate Administrator for NASA's Exploration Systems Mission Directorate. He leads the Agency in the development of the Nation's new spacecraft that will return astronauts to the Moon and travel to Mars and other destinations in the solar system.

Gilbrech previously served as Director of NASA's Stennis Space Center near Bay St. Louis, Missouri, where he provided overall leadership, planning, policy direction, management and coordination for all activities implementing NASA's mission directorates.

Before being named Director of Stennis, Gilbrech served as Deputy Center Director of NASA's Langley Research Center, Hampton, Virginia. Prior to that he was Deputy Director of the NASA Engineering and Safety Center, located at Langley.

Gilbrech started his NASA career in 1991 at Stennis in the area of propulsion test technology. In 1995, he was selected as the Stennis national aerospace plane project manager responsible for the construction, activation and operation of a facility to test actively-cooled structures. Later in 1995, he was named the X33 project manager, responsible for converting the A–1 test stand at Stennis from Space Shuttle main engine testing to linear aerospike turbopump single- and dual-engine testing. From 1998 to 2000, he served as chief of the Propulsion Test Engineering Division within the Propulsion Test Directorate at Stennis.

Gilbrech earned a Bachelor's degree in aerospace engineering from Mississippi State University. He earned Master's and doctorate degrees in aeronautics from the California Institute of Technology with a minor in planetary science.

The recipient of numerous awards, Gilbrech has received NASA's prestigious Outstanding Leadership and Exceptional Achievement Medal.

Chairman UDALL. Thank you for that tutorial. Ms. Chaplain, the floor is yours.

STATEMENT OF MS. CRISTINA T. CHAPLAIN, DIRECTOR, ACQUISITION AND SOURCING MANAGEMENT, GOVERNMENT ACCOUNTABILITY OFFICE

Ms. CHAPLAIN. Thank you. Thanks for inviting me here today to discuss our work related to NASA's future space exploration efforts. We have been focusing on work primarily on the Ares I launch vehicle and the Orion crew exploration vehicle as they are among the first major efforts conducted as part of the Constellation Program and represent a substantial investment. Over $7 billion in contracts has already been awarded and nearly $230 billion is estimated to ultimately be spent over the next two decades for Constellation.

NASA is currently working toward preliminary design reviews for these vehicles. This is a milestone that successful organizations use to make hard decisions about whether a program should proceed forward with development. The phase leading up to a preliminary design review is a time for discovery and risk reduction. As such, it is expected that there will be unknowns as to whether program plans can be executed within schedule goals as well as what they will ultimately cost as practice organizations close these knowledge gaps by the time they commit to programs which is usually shortly after the preliminary design review.

We have identified several issues that should be under close watch for the Ares I and Orion projects leading up to their preliminary design reviews. These include, first, progress and requirements definition and related impacts on weight of the vehicles. NASA cannot accurately estimate cost schedules until requirements are defined. At this time, requirements such as those relating to how the Orion will return to Earth are among those still in development.

Second, progress and technology development, particularly with the J–2X upper-stage engine and the Orion heat shield since they require significant work. Our reviews of space programs consistently find that the later technology discovery occurs in a program, the higher the risk of cost increases and schedule delays.

Third, schedule slippage. Delays in setting requirements in technology development have resulted in some schedule slips which may increase costs. Moreover, there is a high degree of concurrency in both schedules. While this approach can save time, it can also create delays and cost increases since additional rework may be required to address unexpected problems.

Fourth, progress in resolving thrust oscillation programs. As Dr. Gilbrech has just commented, NASA recognizes this is a serious risk and it is taking reasonable measures for dealing with it.

Fifth, progress toward adding testing resources. Existing facilities have been insufficient so far to adequately test the J–2X engine and the heat shield for the Orion. However, NASA has appropriately increased attention to this area, too.

In responding to our recent report on Ares I, NASA agreed that these are high-risk areas and committed to delay preliminary design reviews if it has not yet attained critical knowledge on them. This is important. The long-term nature of the vision, its inherent challenges, and the magnitude of the investment at stake make it vital that the right decisions be made early on and that senior leaders have the right knowledge going forward so they can make informed decisions.

It is also important that NASA continue to be realistic and open about the progress it is making and to be willing to make changes to the program if technical problems cannot be solved with overly compromising performance. This is difficult to do in any large government acquisition; the need to make adjustments is often unwelcome news, particularly if they may require more funding or time than originally promised. But pushing off problems in fear of losing commitments to a program invariably leads to much more time delays and cost growth and thus less resources for other needed investments.

We appreciate the candor of the program officials to date, and we look forward to continued discussions on progress.

This concludes my statement, and I am happy to answer any questions you have.

[The prepared statement of Ms. Chaplain follows:]

PREPARED STATEMENT OF CRISTINA T. CHAPLAIN

Ares I and Orion Project Risks and Key Indicators to Measure Progress

Mr. Chairman and Members of the Subcommittee:

I am pleased to be here today to discuss challenges that the National Aeronautics and Space Administration (NASA) faces in developing the systems to achieve its goals for the President's *Vision for Space Exploration.*[1] We have been focusing our work primarily on the Ares I Crew Launch Vehicle and the Orion Crew Exploration Vehicle,[2] as they are among the first major efforts conducted as part of NASA's Constellation Program to support implementation of the Vision and represent a substantial investment for NASA. Over $7 billion in contracts has already been awarded—and nearly $230 billion is estimated to be ultimately spent over the next two decades. Moreover, NASA is under pressure to develop the vehicles quickly, as the Space Shuttle's retirement in 2010 means that there could be at least a five-year gap in our nation's ability to send humans to space.

In summary, NASA is currently working toward preliminary design reviews for the vehicles—a milestone that successful development organizations use to make hard decisions about whether a program should proceed with development. While this is a phase for discovery and risk reduction, there are considerable unknowns as to whether NASA's plans for the Ares I and Orion vehicles can be executed within schedule goals, as well as what these efforts will ultimately cost. In fact, we do not know yet whether the architecture and design solutions selected by NASA will work as intended. This is primarily because NASA is still in the process of defining both of the projects' performance requirements and some of these uncertainties could affect the mass, loads, and weight requirements for the vehicles. It is also working through significant technical risks, such as oscillation within the first stage of the Ares I vehicle, which computer modeling indicates could cause unacceptable structural vibrations.

NASA is aiming to complete preliminary design reviews for the Ares I and Orion this year, scheduled for August 2008 Ares I and September 2008 respectively, but it will be challenged in doing so given the level of knowledge that still needs to be attained. In addition, to minimize the gap in human space flight caused by the Shuttle's retirement, there is a high degree of concurrency within the projects. Our prior work has shown that concurrent development, especially when new technologies are involved, increases the risk that significant problems will be discovered as the systems' designs are integrated that could result in cost and schedule delays. NASA's schedule leaves little room for the unexpected. If something goes wrong with the development of the Ares I or the Orion, the entire Constellation Program could be thrown off course and the return to human space flight delayed.

NASA recognizes the risks involved with its approach and has taken steps to mitigate some of these risks. It is important that, in mitigating risks, NASA continually assess the viability of its plans for the Ares I and Orion. The current state of play requires that NASA remain open to the possibility that it may need to revisit decisions on its architecture and design as these vehicles are expected to be in use for decades to come and decisions made now will have long-term consequences.

Moreover, with additional significant investment decisions still ahead, it is important that agency decision-makers and Congress maintain clear insight into the progress the projects are making as well as any potential problems. This type of oversight is important, not just for the Ares I and Orion vehicles, but for the entire future exploration effort—since resources available to fund the Vision are constrained, as competition for resources increases within the Federal Government over the next several decades. In this regard, our work has identified specific markers that can be used to (1) assess NASA's progress in closing critical knowledge gaps

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[1] The Vision includes a return to the Moon that is intended ultimately to enable future exploration of Mars and other destinations. To accomplish this, NASA initially plans to (1) complete its work on the international Space Station by 2010, fulfilling its commitment to 15 international partner countries; (2) begin developing a new manned exploration vehicle to replace the Space Shuttle; and (3) return to the Moon in preparation for future, more ambitious missions.

[2] GAO, *NASA: Agency Has Taken Steps Toward Making Sound Investment Decisions for Ares I but Still Faces Challenging Knowledge Gaps,* GAO–08—51 (Washington, D.C.: Oct. 31, 2007) and GAO, *NASA: Long-Term Commitment to and Investment in Space Exploration Program Requires More Knowledge,* GAO–06–817R (Washington, D.C.: July 17, 2006).

and (2) identify issues that could result in cost growth, schedule delays, or decreased performance. In other words, they can be used to assess whether there is a viable business case for pressing forward with the projects.

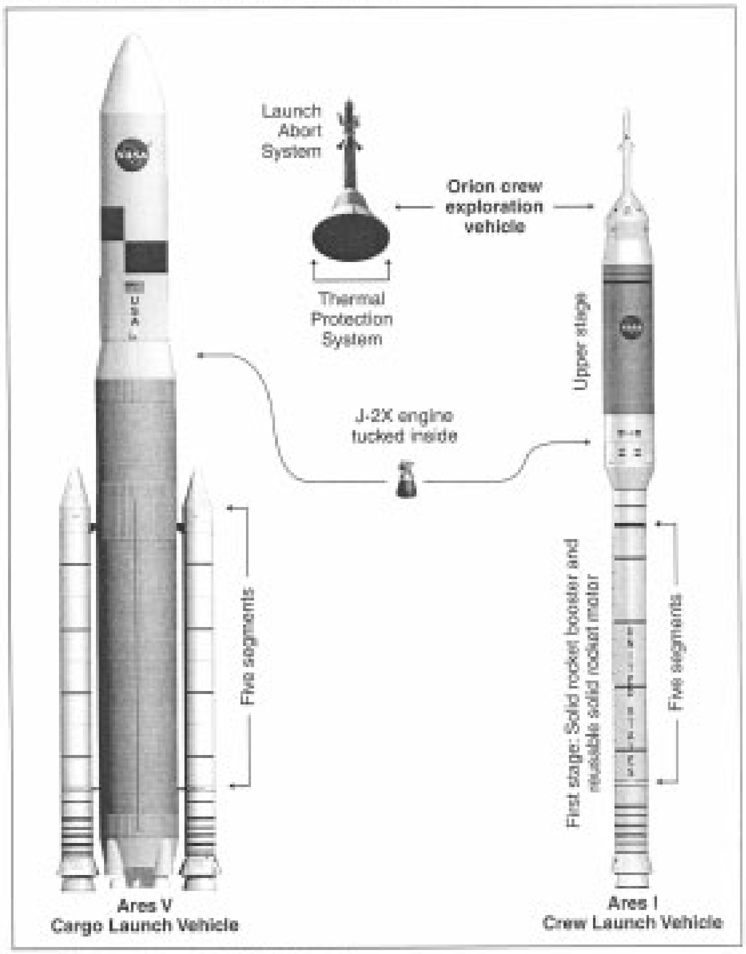
We have issued a number of reports and testimonies that touch on various aspects of NASA's Constellation Program and in particular the development efforts underway for the Orion and Ares I projects. These reports and testimonies have questioned the affordability and overall acquisition strategy for each project. In July 2006 we recommended that NASA modify the Orion Crew Vehicle acquisition strategy to ensure the agency did not commit itself to a long-term contractual obligation prior to establishing a sound business case. Although initially NASA disagreed with our recommendation, the agency subsequently revised its acquisition strategy to address some of the concerns we raised. In October 2007 we recommended that NASA develop a sound business case supported by firm requirements, mature technologies, a preliminary design, a realistic cost estimate, and sufficient funding and time-before proceeding beyond preliminary design review. NASA concurred with this recommendation and subsequently slipped the Ares I preliminary design review from July 2008 to August 2008.

My statement today is based on these products, as well as updated information based on our continual monitoring of the projects at the request of Members of Congress. To conduct these reviews, we analyzed relevant project documentation, prior GAO reports, NASA documents, and contractor information; interviewed program and project officials; and reviewed NASA's risk management system for the Constellation Program. Based on this work, my statement will specifically address the challenges that NASA faces developing the Ares I and Orion vehicles with regard to requirements definition, technology and hardware gaps, cost and schedule estimates, and facilities needs. Further, I will provide key indicators that decision-makers could use to assess risks as the two development efforts move forward. We conducted this performance audit from October 2007 through April 2008 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

In September 2005, NASA outlined an initial framework for implementing the President's *Vision for Space Exploration* in its Exploration Systems Architecture Study. NASA is now implementing the recommendations from this study within the Constellation Program, which includes three major development projects—the Ares I Crew Launch Vehicle, the Orion Crew Exploration Vehicle, and the Ares V Cargo Launch Vehicle as shown in Figure 1.

Figure 1: Overview of Ares I and Orion Projects



Source: GAO analysis and presentation of NASA photos and data.

To reduce cost and minimize risk in developing these projects, NASA planned to maximize the use of heritage systems and technology. Since 2005, however, NASA has made changes to the basic architecture for the Ares I and Orion designs[3] that have resulted in the diminished use of heritage systems. This is due to the ability to achieve greater cost savings with alternate technology and the inability to recreate heritage technology. For example, the initial design was predicated on using the main engines and the solid rocket boosters from the Space Shuttle Program. However, NASA is no longer using the Space Shuttle Main Engines because greater long-term cost savings are anticipated through the use of the J–2X engine. In another example, NASA increased the number of segments on the Ares I first-stage reusable solid rocket booster from four to five to increase commonality between the Ares I and Ares V, and eliminate the need to develop, modify, and certify both a

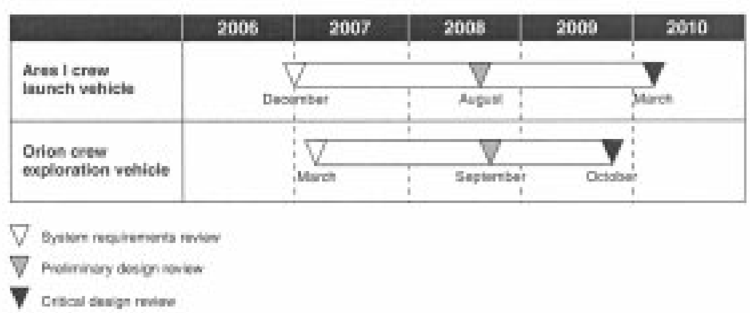
[3] Heritage systems are systems with characteristics similar to the one being developed. A heritage system is often the one the new program is replacing.

four-segment reusable solid rocket booster and an expendable Space Shuttle main engine for the Ares I. Finally, according to the Orion program executive the Orion project originally intended to use the heat shield from the Apollo program as a fall-back technology for the Orion thermal protection system, but was unable to recreate the Apollo material.

NASA has authorized the Ares I and Orion projects to proceed with awarding development contracts. In April 2006, NASA awarded a $1.8 billion contract for design, development, test, and evaluation of the Ares I first stage to Alliant Techsystems. NASA also awarded a $1.2 billion contract for design, development, test, and evaluation of the Ares I upper stage engine—the J–2X—to Pratt and Whitney Rocketdyne in June 2006. NASA is developing the upper stage and the upper stage instrument unit, which contains the control systems and avionics for the Ares I, in-house. However, NASA awarded a $514.7 million contract for design support and production of the Ares I upper stage to the Boeing Company in August 2007. In August 2006, NASA awarded Lockheed Martin a $3.9 billion contract to design, test, and build the Orion crew exploration vehicle.[4] According to NASA, the contract was modified in April 2007, namely by adding two years to the design phase and two test flights of Orion's launch abort system and by deleting the production of an cargo variant for the International Space Station. NASA indicates that these changes increased the contract value to $4.3 billion. Federal procurement data shows that an additional modification has been signed which increased the value of the contract by an additional $59 million.

NASA has completed or is in the process of completing key reviews on both the Ares I and Orion projects. NASA has completed the system requirements review for each project and is in the midst of finalizing the system definition reviews.[5] At the systems requirements review, NASA establishes a requirements baseline that serves as the basis for ongoing design analysis work and systems testing. Systems definition reviews focus on emerging designs for all transportation elements and compare the predicted performance of each element against the currently baselined requirements. Figure 2 shows the timeline for Ares I and Orion critical reviews.

Figure 2: Timeline for Ares I and Orion Critical Reviews (in fiscal years)



Source: GAO analysis of NASA data.

NASA is using its Web-based Integrated Risk Management Application to help monitor and mitigate the risks with the Ares I and Orion development efforts and for the overall Constellation Program. The risk management application identifies and documents risks, categorizes risks—as high, medium, and low based on both the likelihood of an undesirable event as well as the consequences of that event to the project—and tracks performance against mitigation plans. For the Ares I project,

[4] The actual value of the contract could be greater than $3.9 billion if NASA exercises options on the contract for production and sustainment or issues orders against the indefinite delivery/indefinite quantity portion of the contract.

[5] The system requirements review is intended to examine the function and performance requirements defined for the system and the preliminary project plan and ensure that the requirements and the selected concept will satisfy the mission. The system definition review examines the proposed system design and the flow-down of that design to all functional elements of the system. The system requirements review and system definition review process culminates with key decision point B wherein NASA determines the project's readiness to move forward.

the application is tracking 101 risks, 36 of which are considered high-risk areas.[6] For the Orion project, NASA is tracking 193 risks, including 71 high-risk areas.[7] NASA is developing and implementing plans to mitigate some of these risks.

Requirements Setting Is a Primary Challenge for Both the Ares I and Orion Projects

Although project level requirements were baselined at both systems requirements reviews, continued uncertainty about the systems' requirements have led to considerable unknowns as to whether NASA's plans for the Ares I and Orion vehicles can be executed within schedule goals, as well as what these efforts will ultimately cost. Such uncertainty has created knowledge gaps that are affecting many aspects of both projects. Because the Orion vehicle is the payload that the Ares I must deliver to orbit, changes in the Orion design, especially those that affect weight, directly affect Ares I lift requirements. Likewise, the lift capacity of the Ares I drives the Orion design. Both the Orion and Ares I vehicles have a history of weight and mass growth, and NASA is still defining the mass, loads, and weight requirements for both vehicles. According to agency officials, continuing weight growth led NASA to rebaseline the Orion vehicle design in fall 2007. This process involved "scrubbing" the Orion Vehicle to establish a zero-based design capable of meeting minimal mission requirements but not safe for human flight. Beginning with the zero-based design NASA first added back the systems necessary to ensure crew safety and then conducted a series of engineering trade-offs to determine what other systems should be included to maximize the probability of mission success while minimizing the system's weight. As a result of these trade-offs, NASA modified the requirement for nominal landing on land to nominal landing in water, thereby gaining 1500 lbs of trade space in the Orion design.

NASA recognizes that continued weight growth and requirements instability are key risks facing the Orion project and that continued instability in the Orion design is a risk facing the Ares I project. The Ares I and Orion projects are working on these issues but have not yet finalized requirements or design. Our previous work on systems acquisition work shows that the preliminary design phase is an appropriate place to conduct systems engineering to support requirement and resource trade-off decisions. For the Ares I project, this phase is scheduled to be completed in August 2008, whereas for the Orion project, it is September 2008—leaving NASA only four and five months respectively to close gaps in requirements knowledge. NASA will be challenged to close such gaps, given that it is still defining requirements at a relatively high level and much work remains to be done at the lower levels. Moreover, given the complexity of the Orion and Ares I efforts and their interdependencies, as long as requirements are in flux, it will be extremely difficult to establish firm cost estimates and schedule baselines.

Technology and Hardware Gaps Along With Requirements Uncertainty Are Increasing Risk

Currently, nearly every major segment of Ares I and Orion faces knowledge gaps in the development of required hardware and technology and many are being affected by uncertainty in requirements. For example, computer modeling is showing that thrust oscillation within the first stage of the Ares I could cause excessive vibration throughout the Ares I and Orion. Resolving this issue could require redesigns to both the Ares I and Orion vehicles that could ultimately impact cost, schedule, and performance. Furthermore, the addition of a fifth segment to the Ares I first stage has the potential to impact qualification efforts for the first stage and could result in costly requalification and redesign efforts. Additionally, the J–2X engine represents a new engine development effort that, both NASA and Pratt and Whitney Rocketdyne recognize, is likely to experience failures during development. Addressing these failures is likely to lead to design changes that could impact the project's cost and schedule. With regard to the Orion project, there is currently no industry capability for producing a thermal protection system of the size required by the Orion. NASA has yet to develop a solution for this gap, and given the size of the vehicle and the tight development schedule, a feasible thermal protection system may not be available for initial operational capability to the space station. The Table 1 describes these and other examples of knowledge gaps in the development of the Ares I and Orion vehicles.

[6] This is the total number of open risks for the Ares I project as of March 25, 2008. It does not include risks that have been closed or risks that NASA considers sensitive.

[7] This is the total number of open risks for the Orion project as of March 25, 2008. It does not include risks that have been closed or risks that NASA considers sensitive.

Table 1: Examples of Ares I and Orion Technology and Hardware Gaps

Ares I Crew Launch Vehicle	First stage	Current modeling indicates that thrust oscillation within the first stage causes unacceptable structural vibrations. There is a possibility that the thrust oscillation frequency and magnitude may be outside the design limits of the Ares design requirements. A NASA focus team studied this issue and has proposed options for mitigation including incorporating vibration absorbers into the design of the first stage and redesigning portions of the Orion Vehicle to isolate the crew from the vibration. Further, it is unknown how the addition of a fifth segment to the launch vehicle will affect flight characteristics. Failure to completely understand the flight characteristics of the modified booster could create a risk of hardware failure and loss of vehicle control. Ares I relies on hardware adapted from the Space Shuttle program that may not meet qualification requirements. Qualification requirements may be difficult to meet due to the new ascent loads (the physical strain on the spacecraft during launch) and vibration and acoustic environments associated with the Ares I. Resulting redesign and requalification efforts could affect cost and schedule. NASA is currently working to further define the vibration and acoustic environment.
	Upper stage	NASA redesigned the upper stage configuration from two completely separate propellant tanks to two tanks with one common bulkhead. The prior configuration employed a simpler design with a lower manufacturing cost but did not meet mass requirements. The current common bulkhead design involves a complex and problematic manufacturing process that challenged earlier development efforts on the Apollo program. In fact, NASA's Web-based Integrated Risk Management Application indicated that one of the lessons learned from the Apollo program was not to use common bulkheads because they are complex and difficult to manufacture.
	J-2X upper stage engine	Although the J-2X is based on the J-2 and J-2S engines used on the Saturn V and leverages knowledge from the X-33 and RS-68, the number of planned changes is such that, according to NASA review boards, the effort essentially represents a new engine development. NASA and Pratt and Whitney Rocketdyne recognize that some level of developmental problems are inherent in all new engine development programs. As such, the project has predicted that the J-2X development will require 29 rework cycles. In addition, the J-2X faces extensive redesign to incorporate modern controls, achieve increased performance requirements, and meet human rating standards. The J-2X developers also face significant schedule risks in developing and manufacturing a carbon composite nozzle extension needed to satisfy thrust requirements. According to contractor officials, the extension is more than 2 feet—i.e., about one-third—wider in diameter than existing nozzle extensions.
Orion Crew Exploration Vehicle	Launch abort system	Technology development of the launch abort system is being conducted concurrently with design of Orion. Ongoing requirements changes related to the Orion system and its subsystems or development setbacks could (1) prevent some test objectives from being adequately demonstrated during early launch abort system tests, (2) drive the need for additional testing of the abort system, or (3) lead to design revisions or changes to the required number of spares. Any of these possibilities could lead to increased program costs and delays to the flight test schedule. According to NASA officials, the agency is currently assessing alternative designs for the launch abort system to address weight and vibration concerns.
	Thermal protection system	The Orion requires the development of a large-scale ablative thermal protection system. Given the size of the vehicle and the tight development schedule, a feasible thermal protection system may not be available in time for the Orion initial operational capability to the space station. There is currently no industry capability for producing a thermal protection system of the size required by the Orion. Furthermore, heat shield design features required by the Orion, namely the size, have never been proven and must be developed. NASA is currently conducting an advanced development project to mature technologies necessary to meet thermal protection system requirements.

Source: GAO analysis of NASA data.

Constellation Cost Estimates Are Preliminary Due to Requirements Uncertainty

NASA's preliminary cost estimates for the Constellation Program are likely to change when requirements are better defined. NASA will establish a preliminary estimate of life cycle costs for the Ares I and Orion in support of each project's system definition review. A formal baseline of cost, however, is not expected until the projects' preliminary design reviews are completed. NASA is working under a self-imposed deadline to deliver the new launch vehicles no later than 2015 in order to minimize the gap in human space flight between the Space Shuttle's retirement in 2010 and the availability of new transportation vehicles. The Constellation Program's budget request maintains a confidence level of 65 percent (i.e., NASA is 65 percent certain that the actual cost of the program will either meet or be less than the estimate) for program estimates based upon a 2015 initial operational capability. Internally, however, the Ares I and Orion projects are working toward an earlier initial operational capability (2013), but at a reduced budget confidence level—33 percent. However, NASA cannot reliably estimate the money needed to complete technology development, design, and production for the Ares I and Orion projects until requirements are fully understood.

NASA has identified the potential for a life cycle cost increase as a risk for the Orion program. According to NASA's risk database, given the historical cost overruns of past NASA systems and the known level of uncertainty in the current Orion requirements, there is a possibility that Orion's life cycle cost estimate may increase over time. NASA acknowledges that such increases are often caused by the unknown impacts of decisions made during development. One factor currently contributing to cost increases is the addition of new requirements. NASA is working to formulate the best life cycle cost estimate possible during development, is identifying and monitoring costs threats, and is implementing management tools all aimed at addressing this risk.

Schedule Pressures Add Additional Risks for Ares I and Orion

There are considerable schedule pressures facing both the Ares I and Orion projects. These are largely rooted in NASA's desire to minimize the gap between the retirement of the Space Shuttle and availability of the new vehicles. Because of this scheduling goal, NASA is planning to conduct many interdependent development activities concurrently—meaning if one activity should slip in schedule, it could have cascading effects on other activities. Moreover, some aspects of the program are already experiencing scheduling delays due to the fact that high-level requirements are still being defined.

Ares I

The development schedule for the J–2X is aggressive, allowing less than seven years from development start to first flight, and highly concurrent. Due to the tight schedule and long-lead nature of engine development, the J–2X project was required to start out earlier in its development than the other elements on the Ares I vehicle. This approach has introduced a high degree of concurrency between the setting of overall Ares I requirements and the development of the J–2X design and hardware. Consequently, the engine development is out of sync with the first stage and upper stage in the flow-down and decomposition of requirements, an approach our past work has shown to be fraught with risk. NASA acknowledges that the engine development is proceeding with an accepted risk that future requirements changes may affect the engine design and that the engine may not complete development as scheduled in December 2012. The J–2X development effort represents a critical path for the Ares I project. Subsequently, delays in the J–2X schedule for design, development, test, and evaluation would have a ripple effect of cost and schedule impacts throughout the entire Ares I project.

The schedule for the first stage also presents a potential issue for the entire Ares I project. Specifically, the critical design review for the first stage is out of sync with the Ares I project-level critical design review. NASA has scheduled two critical design reviews for the first stage. The first critical design review is scheduled for November 2009, five months before the Ares I project critical design review. At this point, however, the project will not have fully tested the first stage development motors. The second critical design review, in December 2010, occurs after additional testing of developmental motors is conducted. By conducting the Ares I critical design review before the first stage project critical design review, the project could prematurely begin full-scale test and integration activities a full nine months before the first stage design has demonstrated maturity. If problems are found in the first stage design during the later testing, implementing solutions could result in costly rework and redesign and delay the overall project schedule.

Orion

Cost and schedule reporting on the Orion project indicates that the Orion project's efforts to mature requirements and design and to resolve weight issues is placing pressure on the Orion schedule. Specifically, activities aimed at assessing alternate designs to reduce overall vehicle mass, rework to tooling concepts, and late requirements definition have contributed to the project falling behind schedule. Further, the Orion risk system indicates that schedule delays associated with testing may occur. The current Orion design has high predicted vibration and acoustic levels. Historically, components designed and qualified for uncertain vibration and acoustic environments have resulted in some failures and required subsequent redesign and retest. Failures during qualification testing of Orion components may lead to schedule delays associated with redesigning components.

NASA's Administrator has publicly stated that if Congress provided the Agency an additional $2 billion that NASA could accelerate the Constellation program's initial operational capability date to 2013. We believe that this assessment is highly optimistic. The development schedule for the J–2X engine, the critical path for the Ares I development, is already recognized as aggressive, allowing less than seven years for development. The development of the Space Shuttle Main engine by comparison took nine years. Further, NASA anticipates that the J–2X engine is likely to require 29 rework cycles to correct problems identified during testing. Given the linear nature of a traditional test-analyze-fix-test cycle, even large funding increases offer no guarantee of program acceleration, particularly when the current schedule is already compressed and existing NASA test facilities are already maximized.

Test Facilities for Ares I and Orion Insufficient

According to NASA, at this time, existing test facilities are insufficient to adequately test the Ares I and Orion systems. Existing altitude test facilities are insufficient to test the J–2X engine in a relevant environment. To address this issue, NASA is in the process of constructing a new altitude test facility at Stennis Space Center for the J–2X. Also, current facilities are inadequate to replicate the Orion vibration and acoustic environment. Further, Pratt and Whitney Rocketdyne—the J–2X upper stage engine contractor—indicated that existing test stands that could support J–2X testing will be tied up supporting the Space Shuttle program until 2010. NASA has taken steps to mitigate J–2X risks by increasing the amount of component-level testing, procuring additional development hardware and test facilities, and working to make a third test stand available to the contractor earlier than originally planned. NASA has compensated for this schedule pressure on the Ares I project by adding funds for testing and other critical activities. But it is not certain that added resources will enable NASA to deliver the Ares I when expected.

With respect to Orion's thermal protection system, facilities available from the Apollo era for testing large-scale heat shields no longer exist. Therefore, NASA must rely on two facilities that fall short in providing the necessary capability and scheduling to test ablative materials needed for Orion. Additionally, NASA has no scheduled test to demonstrate the thermal protection system needed for lunar missions. NASA is exploring other options, including adding a lunar return flight test and building a new improved test facility. Due to the scheduled first lunar flight, any issues identified during such testing would need to be addressed in the time between the flight test and the first flight.

Oversight Based on Best Practices and Key Indicators Important for Program Success

NASA is poised to invest a significant amount of resources to implement the Vision over the long-term and specifically to develop the Ares I and Orion projects over the next several years. Accordingly, you asked us to articulate indicators that Congress could use to assess progress. Our prior work has shown that investment decisions of this magnitude need to be based on an established and executable business case and that there are several key indicators that Congress could be informed of to assess progress throughout development. These include areas commonly underestimated in space programs, such as weight growth and software complexity, as well as indicators used by best practice organizations to assess readiness to move forward in the development cycle. Space programs which we have studied in detail in the past have tended to underestimate cost in some of these areas.

Weight Growth

Our previous work on government-funded space systems has shown that weight growth is often not anticipated even though it is among the highest drivers of cost growth for space systems. Weight growth can affect the hardware needed to support a system, and, in the case of launch vehicles, the power or thrust required for the system. As the weight of a particular system increases, the power or thrust required for that system will also increase. This could result in the need to develop additional power or thrust capability to lift the system, leading to additional costs, or to stripping down the vehicle to accommodate current power or thrust capability. For example, NASA went through the process to zero-base the design for the Orion to address weight concerns. Continual monitoring of system weight and required power/thrust, as well as margins or reserves for additional growth, can provide decision-makers with an indicator of whether cost increases can be anticipated.

Software Complexity

The complexity of software development on a system, often denoted by the number of lines of code on a system, can also be used as an indicator to monitor whether a program will meet cost and schedule goals. In our work on software development best practices, we have reported that the Department of Defense has attributed significant cost and schedule overruns on software-intensive systems to developing and delivering software. Generally, the greater the number of lines of code, the more complicated the system development. Changes to the amount of code needed to be produced can indicate potential cost and schedule problems. Decision-makers can monitor this indicator by continually asking for information on the estimated amount of code needed on a system and inquiring about any increases in need and their impact on cost and schedule.

There are other areas, such as the use of heritage systems and industrial base capability that are commonly underestimated in space programs as well. However, weight increases and software growth are more quantifiable and thus useful for oversight purposes.

Indicators That Can be Used to Assess Knowledge Gap at Key Junctures

Additionally, since the mid-1990s, GAO has studied the best practices of leading commercial companies. On the basis of this information, and taking into account the differences between commercial product development and major federal acquisitions, we have outlined a best practices product development model—known as a knowledge-based approach to system development. This type of approach calls for investment decisions to be made on the basis of specific, measurable levels of knowledge at critical junctures before investing more money and proceeding with development.

Importantly, our work has shown the most leveraged decision point is matching the customer's needs with the developer's resources (time, dollars, technology, people, etc.) because it sets the stage for the eventual outcome—desirable or problematic. The match is ultimately achieved in every development program, but in successful development programs, it occurs before product development is formally initiated (usually the preliminary design review). If the knowledge attained at this and other critical junctures does not confirm the business case on which the acquisition was originally justified, the best practice organizations we have studied do not allow the program to go forward.

We have highlighted the three critical junctures at which developers must have knowledge to make large investment decisions-the preliminary design review, the critical design review, and the production review-and the numerous key indicators that can be used to increase the chances of successful outcomes.

In assessing the Orion and Ares programs, the Congress and NASA decision-makers can use these indicators in order to reliably gauge whether there is a sufficient business case for allowing the programs to proceed forward.

Preliminary design review: Before product development is started, a match must be made between the customers' needs and the available resources—technical and engineering knowledge, time, and funding. To provide oversight at this juncture, NASA could provide Congress with information to verify that the following have indicators been met:

- All critical technologies are demonstrated to a high level of technology maturity, that is demonstrated that they can perform in a realistic or, more preferably, operational environment. A technology readiness level 6 or 7 would indicate that this has been achieved. One approach to ensure that technology readiness is reliably assessed is to use independent testing;
- Project requirements are defined and informed by the systems engineering process;
- Cost and schedule estimates established for the project are based on knowledge from the preliminary design using systems engineering tools;
- Additional resources are in place, including needed workforce, and a decision review is conducted following completion of the preliminary design review.

A critical enabler for success in this phase of development is performance and requirements flexibility. Customers and product developers both need to be open to reducing expectations, deferring them to future programs, or to investing more resources up front to eliminate gaps between resources and expectations. In successful programs we have studied, requirements were flexible until a decision was made to commit to product development because both customers and developers wanted to limit cycle time. This makes it acceptable to reduce, eliminate, or defer some customer wants so that the product's requirements could be matched with the resources available to deliver the product within the desired cycle time.

Critical design review: A product's design must demonstrate its ability to meet performance requirements and be stable about midway through development. To provide oversight at this juncture, NASA could provide Congress with information to verify that the following indicators have been met:

- At least 90 percent of engineering drawings are complete;
- All subsystem and system design reviews have been completed;
- The design meets requirements demonstrated through modeling, simulation, or prototypes;
- Stakeholders' concurrence that drawings are complete and producible is obtained;

- Failure modes and effects analysis have been completed;
- Key system characteristics are identified;
- Critical manufacturing processes are identified;
- Reliability targets are established and a growth plan based on demonstrated reliability rates of components and subsystems is developed; and
- A decision review is conducted following the completion of the critical design review.

Production Review: The developer must show that the product can be manufactured within cost, schedule, and quality targets and is demonstrated to be reliable before production begins. To provide oversight at this juncture, NASA could provide Congress with information to verify that the following indicators have been met:

- Manufacturing processes have been demonstrated;
- Production representative prototypes have been built;
- Production representative prototypes have been tested and have achieved reliability goals;
- Production representative prototypes have been demonstrated in an operational environment through testing;
- Statistical process control data have been collected;
- Critical processes have been demonstrated to be capable and that they are in statistical control;
- A decision review is conducted following completion of the production readiness review.

Over the past two years, we have recommended that NASA incorporate a knowledge-based approach in its policies and take steps to implement this type of approach in its programs and projects.[8] NASA has incorporated some knowledge-based concepts into its acquisition policies. For example, NASA now requires a decision review between each major phase of the acquisition life cycle and has established general entrance and success criteria for the decision reviews. In addition, we have reported that this type of approach is being embraced by the Ares I project.

Concluding Observations

In conclusion, the President's *Vision for Space Exploration* is an ambitious effort, not just because there will be technical and design challenges to building systems needed to achieve the Vision's goals, but because there are limited resources within which this can be accomplished. Moreover, the long-term nature of the Vision means that commitments for funding and to the goals of the Vision will need to be sustained across presidential administrations and changes in congressional leadership. For these reasons, it is exceedingly important that the right decisions are made early on and that decision-makers have the right knowledge going forward so that they can make informed investment decisions.

In looking at the first major investments, the Ares I and Orion projects, it is important to recognize that they are risky endeavors, largely due to their complexity, scope, and interdependencies. It is also important to recognize that the desire to minimize the gap in human space flight adds considerable risk, since it could limit NASA's ability to study emerging problems and pursue alternative ways of addressing them. For these reasons, as well as the magnitude of investment at stake, it is imperative that NASA be realistic and open about the progress it is making and to be willing to make changes to the architecture and design if technical problems cannot be solved without overly compromising performance. Additionally, Congress needs to be well-informed about the extent to which knowledge gaps remain and what tradeoffs or additional resources are needed to close those gaps and to support changes if they are determined to be necessary. The upcoming preliminary design review milestones represent perhaps the most critical juncture where these assessments can take place and where hard decisions can be made as to whether the programs should proceed forward. It may well be the last opportunity to make significant adjustments before billions of dollars are spent and long-term commitments become solidified.

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[8] GAO, *NASA: Implementing a Knowledge-Based Acquisition Framework Could Lead to Better Investment Decisions and Project Outcomes,* GAO–06–218 (Washington, D.C.: Dec. 21, 2005); GAO, *NASA: Long-Term Commitment to and Investment in Space Exploration Program Requires More Knowledge,* GAO–06–817R (Washington, D.C.: July 17, 2006); and GAO, *NASA's James Webb Space Telescope: Knowledge-Based Acquisition Approach Key to Addressing Program Challenges,* GAO–06–634 (Washington, D.C.: July 14, 2006).

Mr. Chairman, this concludes my prepared statement. I would be pleased to answer any questions that you may have at this time.

Individuals making key contributions to this statement include James L. Morrison, Meredith A. Kimmitt, Lily Chin, Neil Feldman, Rachel Girshick, Shelby S. Oakley, and John S. Warren, Jr.

BIOGRAPHY FOR CRISTINA T. CHAPLAIN

Ms. Chaplain currently serves as a Director, Acquisition and Sourcing Management, at the U.S. Government Accountability Office. She has responsibility for GAO assessments of military and civilian space acquisitions, other National Aeronautical Space Administration programs, and DOD space science and technology programs. Ms. Chaplain has also led a variety of DOD-wide contracting-related and best practice evaluations for the GAO. Before her current position, Ms. Chaplain worked with GAO's financial management and information technology teams. Ms. Chaplain has been with GAO for 17 years. She received a Bachelor's degree, *magna cum laude,* International Relations from Boston University and a Masters Degree in Journalism from Columbia University.

Chairman UDALL. Thank you very much. Dr. Hinners, the floor is yours.

STATEMENT OF DR. NOEL W. HINNERS, INDEPENDENT CONSULTANT

Dr. HINNERS. Good morning, Mr. Chairman, Members of the Subcommittee. I am pleased to be here today to share with you some of my perceptions of aspects of NASA's Exploration Program. Those include the incorporation of science in exploration, the current architecture, and international cooperation.

Mr. Feeney, I appreciate your recognition of the Gator. I also propose that the Gator might be a good logo for the Congressional witness protection program.

Ever since Sputnik, there has been a not always constructive tension between space science and human space flight. This is based on the fact that they are largely two different cultures driven by different motivations. Each has much to offer the other as was early demonstrated in the Apollo program during which incredible leaps of scientific knowledge accrued, despite the fact that Apollo was politically motivated.

Science also became a major component of Skylab, Shuttle, Space Lab, and the International Space Station. The National Research Council Space Studies Board undertook a major review which I had the honor of chairing of science to human space flight for inhuman space flight in the 1990s with the goal of improving science contributions to human space flight and gaining from it. In conducting the study, it became evident that there are management principles that, if followed, improve the return on investment. Those formed part of the basis of the management recommendations in the recent Space Studies Board Report, The Scientific Context for the Exploration of the Moon.

They were extended to account for specifics of the proposed lunar exploration architecture. Briefly we propose that NASA develop an integrated human robotic program, recognizing the incredible leap of capability in robotics as evidenced by the current Mars exploration rovers. Making clear the priority between multiple goals of exploration is essential to minimizing misunderstandings, for example, a lunar outpost primarily as a stepping stone preparation for eventual Mars human exploration versus sortie missions which are primarily for science benefit.

Establishing an Apollo-style management structure can help in productively merging the two cultures of science and human space flight. Given the almost 50 years between Apollo and current plans for return to the Moon by 2020 or so, it is imperative to bring advanced technology and instrumentation into play both for lunar surface applications and for upgrading the capability to analyze return samples. Many of these recommendations have major budget implications for both NASA's exploration mission and science mission directorates. Given the already-stressed NASA budget, it is not at all clear that NASA can implement an effective lunar exploration program. Its goals are more ambitious than Apollo, yet without the generous funding that enabled Apollo. A go-as-you-pay philosophy will ultimately cost much more than an optimally funded program as we have so painfully seen with the International Space Station.

The vision for space exploration contains a goal eventually exploring Mars with humans, a goal that today is impossible to accomplish in a technical, if not budgetary, sense. The lunar architecture for exploration is then based largely on the precept of using an incremental approach to developing the eventual capability of exploring Mars with humans. The overall planning implies a leap from lunar exploration to going to Mars some time in the decade of the '30s. Given that the lunar program can develop only a very small part of the capability to explore Mars, the absence of a stepwise approach using, for example, missions to libration points and/or asteroids, begs for development of a total exploration architecture. Such should include a lunar exit strategy that will avoid the kinds of issues we now face in trying to transition from the Shuttle and the Space Station.

We must not ignore the contributions we have made to eventual human exploration of Mars by the Robotic Mars Exploration Program. It is a highlight of NASA's programs, one that has truly captured the public interest. It is revealing a Mars not envisioned a short four years ago and provides further reason to believe that Mars holds the greatest likelihood of advancing our understanding for the potential of life originating elsewhere than on Earth. Recent NASA cuts to that program are ill-founded and have the prospects for doing serious damage, just as the plans for a Mars sample return have been rejuvenated. A well-structured, properly funded and thus vigorous Mars robotic program will add immensely to determining what it is that humans will eventually do on Mars, and as important, obtain data critical to determining the very feasibility of such.

NASA's program plans are clearly ambitious. Required and desirable is that many of them be done as international collaborations. This can take advantage of both the increased abilities and desires of potential partners. Obtaining program commitments and proper budgetary support in which Congress can help and relieving some of the more burdensome aspects of the International Traffic and Arms Regulations can go far to help bring about productive collaborations.

Thank you, Mr. Chairman, Members of the Subcommittee.

[The prepared statement of Dr. Hinners follows:]

PREPARED STATEMENT OF NOEL W. HINNERS

Mr. Chairman and Members of the Subcommittee, I thank you for inviting me here to testify today. I am Noel Hinners, an independent consultant on aerospace, working primarily with NASA and several of its contractor community. Starting in 1963, I have had the incredible privilege of participating in the Nation's human and robotic space program, first on the science associated with Apollo and subsequently as NASA's Associate Administrator for Space Science (1974–1979) and Director of Goddard Space Flight Center (1982–1987). Between those two careers, I saw first-hand the public impact of our space and aeronautics programs as Director of the Smithsonian National Air and Space Museum (1979–1982) and the inspirational influence on students in association with my activity at the University of Colorado's Laboratory for Atmospheric and Space Physics and its Aerospace Engineering Sciences Department. A post-NASA career with Lockheed Martin's Civil Space taught me the importance, intricacies and perspective of working with NASA's contractor community. In aggregate, these experiences molded me into an advocate of both human and robotic space exploration and provided the foundation for a belief that a synergistic collaboration between the historically two cultures is in the Nation's best interest.

I will now address the specific questions you posed in your invitation letter requesting that I testify before you today.

Management of Science in the Vision for Space Exploration

You asked that I elaborate on the management recommendations in *The Scientific Context for the Exploration of the Moon* that might optimize the scientific return of the *Vision for Space Exploration* (VSE) and to discuss the lessons learned from the Apollo program. Before going into the specifics, I'd like first to set the context for the recommendations.

The management recommendations are based largely upon the third report issued in the 1990's by the NRC Space Studies Board Committee on Human Exploration (CHEX), a committee that I chaired. The impetus for the CHEX study was the short-lived Space Exploration Initiative (SEI) of 1989 and although the SEI did not survive we felt that it was only a matter of time before a reincarnation would occur. We thus took advantage of the "lull" and produced our study. The recent re-look convinces me that the conclusions remain valid and do indeed apply to the VSE.

Our overall intent was to better define the role of science in human space flight and to reduce the historical friction existing between the "two cultures" of robotic and human space flight. It was our conviction that by so doing there would be improvement in the science return from and contributions to human space exploration. The management report was not initially envisioned; rather it was an outgrowth of our two earlier studies on science prerequisites for and science enabled by human exploration during which it became apparent that the quality of the science accomplished on human space flight programs was in large part a function of how it was organized and implemented. Thus we (qualitatively) assessed the science accomplished on Apollo, Apollo Soyuz Test Project (ASTP), Skylab and Shuttle/Spacelab and correlated our findings with the management structures and funding sources. The overall conclusion was that the Apollo Program, after many fits and starts in the early to mid-60's, evolved an excellent model for productively integrating science requirements and implementation into human space flight and that deviations from that model contributed to a lessening of the science quality and in the overall satisfaction of the science community.

It is instructive to elucidate some key aspects of the Apollo model to aid in assessing the applicability to the VSE. Those include the organizational elements and funding. Human space flight in Apollo was the purview of the Office of Manned Space Flight (OMSF) under Dr. George Mueller. It in turn had an experienced, technically and managerially strong Apollo Program Office at Headquarters, led through Apollo 11 by Apollo Program Director Gen. Sam Phillips and subsequently by Dr. Rocco Petrone. The Apollo Program Office included an Apollo Lunar Exploration Office which incorporated a novel management approach: the science and engineering staff of the Apollo Lunar Exploration Office reported jointly to the Office of Space Science and Applications (OSSA) and to the OMSF. Science goals, objectives, prioritization and requirements, science and scientist selection and analysis of data were the prerogative of OSSA and conformed to its established policies and procedures. Mission implementation, including engineering and operations, was the responsibility of the OMSF. This arrangement proved on balance to be congenial and cooperative. It does not mean that there were no disagreements or frustrations but there were clear paths to issue resolution with no ambiguity on decision authority: Dr. Mueller. He was advised by his Manned Space Flight Experiments Board which dealt with science, technology and engineering experiments and which included representatives from the science and technology organizations. Dr. Mueller also had a Science and Technology Advisory Committee led by Dr. Charles Townes that provided advice directly to him on science in the Apollo program. In Dr. Mueller's words: "I set up the Science and Technology Advisory Committee to be sure that we incorporated the maximum and the best possible science in the Apollo program."

Many were the vigorous discussions of what to do on the Moon, how to do it and where to go. The mission implementation was largely through the Johnson Space Center. A key success element in the view of CHEX was the establishment at JSC of a science division headed by an experienced scientist. This gave an in-house voice to science and provided expert liaison with the OSSA and the external science community. This was most effectively augmented by the establishment of the geographically adjacent Lunar Science Institute (now the Lunar and Planetary Institute). These two organizational elements provided a degree of science ownership and buy-in in an otherwise engineering dominated culture.

Returning now to the report, the first management recommendation is:

NASA should increase the potential to successfully accomplish science in the VSE by (1) developing an integrated human/robotic science strategy,(2) clearly stating where science fits in the Exploration Systems Mission Directorate's (ESMD's) goals and priorities, and (3) establishing a science office embedded in the ESMD to plan and implement science in the VSE. Following the Apollo model, such an office should report jointly to the Science Mission Directorate and the ESMD, with the science office controlling the proven end-to-end science process.

There is a process underway in NASA to develop such an integrated human/robotic science strategy. The Lunar Reconnaissance Orbiter, scheduled for launch late this year, has finally had its management approach resolved with ESMD responsible for the first year of operations and data collection needed to satisfy their requirements. LRO will then be transferred to SMD for continued use as a science mission. Among numerous collaborative efforts within NASA there is an ESMD/SMD Outpost Science and Exploration Working Group. The recently established NASA Lunar Science Institute is jointly supported by SMD and ESMD. Further, the Lunar Exploration Analysis Group brings together both internal and external scientists into ESMD/SMD planning. It is groups such as these that will help clarify the relative roles of lunar science and exploration preparation.

An office equivalent to the Apollo Lunar Exploration Office does not exist within ESMD. I recognize that we are over a decade away from implementation of the human element of lunar exploration. However, establishing the nucleus of such an office now could do much to establish the path, clarify processes and give further impetus to the integration of science into exploration. It would solidify a management structure that just might survive the all-to-frequent changes in leadership at the AA level in NASA.

Recommendation 2 addresses the need to initiate early the process of landing site selection and mission planning. This does not mean identifying now the specific sites where crews will land but should include developing criteria that can lead to optimization of the science in the context of the overall exploration goals and priorities. Such will be significantly different for sortie missions and an outpost. Sortie missions, to the degree that they occur, will be largely science-driven while an outpost will be driven as much or more so by exploration preparation. Site selection will be an ongoing process with results influenced greatly by data yet to be acquired (e.g., is there really accessible water in the polar regions and is In Situ Resource Utilization a practical objective?). It is possible that the requirements for "Exploration Preparation," a major VSE theme, can be met by one of a large number of lunar site locations and that the science optimization can play a prime role in which specific location is finally selected. The considerations for an outpost location should include the potential to serve as a servicing and laboratory node for robotic exploration.

Recommendation 3 relates to the need to identify and develop advanced technology and instrumentation. This recognizes that there does not exist an inventory of applicable technology and capability. This results from what will be, by 2019, close to a 50-year gap in human and most robotic lunar exploration. It also derives from a much changed capability from the days of Apollo and envisions a more collaborative robotic/human effort. For example, much of the Apollo lunar surface traverse time was used in going to locations selected on the basis of relatively low resolution, panchromatic photography. Today, through the use of instrumentation such as on LRO and the use of Mars Exploration Rover (MER) type rovers, one could identify in detail locations worthy of detailed follow-up by astronauts. As a thought experiment, think of the MER sites on Mars and how efficiently we could explore those sites with astronauts. Similarly, emplacement of some geophysical instrumentation can be done robotically rather than primarily by Apollo ALSEP-type deployments; indeed, that is the basis of the recent SMD announcement of initiation of two elements of a robotically emplaced geophysical network. If a pressurized crewed rover is developed, the potential to use it in a robotic mode when not crewed can greatly extend the science utility of either an outpost or sortie missions.

Our last recommendation, 4, urges a thorough review and subsequent upgrading of the capability to collect, preserve, analyze and curate lunar samples both on the Moon and upon return of the samples to Earth. This is based on the fact that the major science return from Apollo was in the immediate and ongoing analyses of the samples, an activity that continues today. The Lunar Curatorial Facility at JSC is the key to this. While it has maintained a degree of modernity through the ongoing curation of Apollo samples, meteorites, cosmic dust and solar wind, it is not prepared to handle the "next generation" of acquired lunar samples. An outpost on the Moon will add further challenge in meeting the need for conducting preliminary analyses and curation on the Moon, both to enable real-time feedback into the exploration and to "high-grade" samples for return to Earth.

I will now address the second tangible, funding. This was not an inherent part of the NRC study yet the budgetary implications of the study are enormous with major implications for the scientific success or lack thereof in the exploration program.

Funding of lunar science in conjunction with human exploration in the VSE is a major problem not yet overtly faced by NASA. It is a latent issue guaranteed to create major tensions some five or so years downstream and can negate the best of intentions. This problem did not exist in Apollo; had it, I can only believe that Apollo would not have been nearly as successful as turned out. Apollo was extremely well funded and it paid for the implementation of essentially all of the Apollo science (OSSA funded the science and Apollo site-certification robotic precursors such as the Rangers, Surveyors and Lunar Orbiters). Today ESMD is having difficulty adequately funding (on a rational development schedule) the infrastructure basics of the future lunar architecture: Ares I and V, Orion and Altair. Until those developments are largely completed, there is not much room to start development of "auxiliary" equipment, i.e., that which allows one to use the infrastructure for a purpose.

The seeds of the science related funding problem are evident in the elements of the lunar architecture. The priority is to establish a lunar outpost with the goal of learning how to live and operate for extended time on a planetary surface. It is stated that such an outpost provides needed experience as a feed-forward to eventual human exploration of Mars. Many of the presumed auxiliary equipments potentially useful for scientific exploration—rovers, advanced habitats, advanced EVA suits, lab facilities, etc.—are "open for contribution" from potential international partners. Let us hope that such contributions are offered in a timely manner. An ancillary, not insignificant, funding issue is recognizable in the discussions of "sortie" missions. Sorties are advocated by the science community to accomplish the exploration of multiple, geologically diverse lunar sites for relatively short time periods (up to seven days); this is essentially an extension of Apollo type missions. ESMD indicates that it is planning to have a capability in the Lunar Surface Access Module, (LSAM, recently named Altair), to conduct sortie missions. Consider, however, that the Administrator of NASA has noted many times that we are not returning to the Moon for science. Fair enough (although the Lunar Architecture Global Exploration Strategy lists "Science Knowledge" as one of the prime themes). At the Tempe lunar workshop in February of 2007, the Administrator (via call-in) noted that scientists are free to buy a sortie mission at some $2B per sortie which, he noted, is similar to the cost of a Science Mission Directorate flagship mission. I do not anticipate that SMD will pay for such a privilege very frequently given that the bulk of lunar science is not demonstrably competitive with the other space science at that level of funding. I note that one might make the case for the science value of a sortie mission to the South Pole-Aitken Basin which if done robotically might well be in the flagship category. I do not want to leave an impression that there is not good lunar science to be done. There is, as is detailed in the NRC report *The Scientific Context for the Exploration of the Moon,* and much of which can and ought to be done robotically. Indeed, the recently proposed on-going lunar robotic mission budget of ?$60M per year, in conjunction with international missions, is a reasonable start on that approach. How much lunar science is worth doing depends on its relative competitiveness with all that is on the plate in SMD. This is the basis of a recommendation in the 2005 NRC report *Science in NASA's Vision for Space Exploration:* "Science that is enabled by human exploration is properly competed directly with "decadal survey" science and then ranked and prioritized according to the same rigorous criteria."

There is no implication in the above that either the NASA Administrator or those in ESMD are anti-science. Quite the contrary: Administrator Griffin has unabashedly supported Earth and space science and ESMD is working closely with SMD to understand and define a science component for exploration. It is simply a matter of facing a stark fact: NASA's budget today and in the outlook is grossly inadequate to enable NASA to properly fund the human lunar exploration to accomplish significant science. The import of that conclusion is considerable—and ironic: we are not returning to the Moon to do science yet the conduct of science is virtually the singular major activity associated with lunar exploration other than attending to the mechanics of living there (in situ resource utilization has yet to be convincingly developed as a near-term major activity either in an engineering or economic sense).

Observations on the Exploration Architecture

The second topic I have been asked to address is my perspective regarding the exploration architecture and how it relates to preparing for exploration beyond the Moon. As a starting point I take the *NASA Authorization Act of 2005:* "The Administrator shall establish a program to develop a sustained human presence on the Moon, including a robust precursor program to promote exploration, science, commerce and U.S. preeminence in space, and as a stepping stone to future exploration of Mars and other destinations." This indeed sets the high-level goal. I and many others assume Mars as the prime and tantalizing future destination yet also include Near Earth Objects (NEOs) and Sun-Earth libration points (with astronomical observatory servicing/construction potential) as among other feasible and desirable destinations for both science and stepping stone reasons. The Global Exploration Strategy theme of "Exploration Preparation" is supportive of this in theory yet the Exploration Systems Architecture Study of Nov. 2005 contains no mention of NEOs or Sun-Earth libration points. It thus implies a leap directly from the Moon to Mars.

How does lunar exploration serve as a stepping stone? In the lunar architecture plans (e.g., LAT2) there is an incorporation of Moon to Mars stepping-stone elements and the very selection of a focus on outposts instead of sortie missions is based on the greater contribution of outposts vis-á-vis sorties to exploration beyond the Moon. That said, I believe that we do not yet have as comprehensive an understanding as one should have. of how the Moon—or any other pre-Mars destination—can optimally contribute to getting to Mars. There does not today exist a inclusive, fully-developed, accepted long-range (e.g., 30-year) architecture for exploration, a void that hinders more efficiently structuring a lunar architecture and strategy and getting the most out of it for "Exploration Preparation." In an ideal world in which one aspires to the human exploration of Mars as the goal for which we are incrementally preparing, one would first establish the requirements for Martian human exploration and feed them back into "precursor" architectures for the Moon and other pre-Mars destinations and for preparatory "precursor" robotic exploration of Mars. Recognizing that need, last year the NASA Administrator asked that an updated Mars reference architecture be developed. Work was initiated and an excellent start made. It is thus unfortunate that the work on an updated Mars Design Reference Mission has been halted just when it was starting to be productive in developing requirements, assessing risks and identifying technology and precursor needs that could be used to guide precursor lunar and other architectures. It is not NASA's choice to stop: it is a direct result of language in the *Appropriations Act of 2008:* "Finally, bill language is included, as proposed by the House, prohibiting funding of any research, development, or demonstration activities related exclusively to the human exploration of Mars." That direction is not in the best interests of structuring an integrated human exploration program architecture that gives the Nation an optimum return on its investment. I urge the Committee to reverse the restriction and let NASA conduct those studies essential to providing the best possible total, integrated human exploration program. Indeed, I would go so far as to suggest the Committee direct NASA to conduct such studies and demonstrate to the Congress that there is a logical, economically feasible, technically effective progression of human exploration endeavors that is efficient and in consonance with the Authorization of 2005.

The lack of an updated detailed Mars architecture does not prohibit top-level strategizing and planning for exploration beyond the Moon. Indeed, NASA has taken a major first step in that direction in its determination that the basic launch capability being structured for the return to the Moon must have applicability to Mars. The planned heavy-lift cargo vehicle Ares V clearly fits that requirement. There are many other things we know today that are obviously required and that have feed-back implications: long-duration human flight (up to three years) with attendant crew-related questions dealing with radiation, micro-gravity, isolation, health and safety, etc., and those treating the hardware and software systems that support the exploration. There are "operational" considerations: aerocapture vs. direct entry, the actual entry, descent and landing; the potential use of in situ resources to reduce mass (thus cost), logistics, science planning, the effects of dust, possible toxicity of Martian soil, mobility and trafficability, etc.

A lunar outpost-centric program can contribute to learning about the long-duration planetary surface operations component of "Exploration Preparation." It will not contribute to many of the key elements noted above. The lander, Altair, e.g., has virtually no applicability to landing humans on Mars. Today, budgets aside, we dare not embark on a Mars human exploration program despite some ill-founded hallucinatory calls external to NASA for so doing. We simply cannot do it. As the top example of non-readiness, consider safe and reliable long-duration space flight such as required for Mars. We simply do not have crews or crew systems that are "flight qualified" for three year sojourns. Short-duration flights to the Moon will not add to that development any more that Apollo did. Jumping right to development of a three-year Mars system, while theoretically feasible, is not reasonable. Rather, a step-wise, evolutionary development building on Orion in a "Block X" approach would be more rational. This is where a long-range, comprehensive exploration architecture development might show, for example, how using first the International Space Station as a realistic prototyping local (getting some ROI on the ~ $35B investment), thence proceeding to libration missions of ~ a month's duration followed by longer duration asteroid missions of several months leads more realistically to Mars. Such a sequence could be accomplished over a span of some 10 to 15 years. It is also consistent with an obvious conclusion that one gets the most data at lowest cost on Earth, and progressively less data more expensively as one moves to LEO, Moon, NEO or L-point and, finally, Mars. The obvious question is not so much one of can such a plan be constructed; rather it is can such a plan be implemented while conducting a lunar program that appears capable of consuming the entire available budget through at least 2030. This question is part of what lurks behind the sometimes heard phrase "stuck on the Moon." Ideally the lunar program would be constructed and implemented in a way that allows for simultaneous development of non-lunar, pre-Mars missions. Budget reality might well preclude that approach, a likelihood that also applies to the simultaneous development of a Mars capability as implied in the ESAS. All of this suggests avoiding a large build-up of lunar infrastructure. In any case, one should have a lunar program exit strategy: when will the lunar program provide the required data in support of "Exploration Preparation" and how does one disengage from the Moon? Hoped for turn-over of lunar infrastructure to commercial and/or international partners does not seem particularly realistic.

Thus far I've discussed mostly the human mission aspect of exploration architectures. There is a corollary aspect that begs discussion and that is the role of robotics. Noted above is the new lunar robotic program and ESMD lunar thinking considers using robotics in association with an outpost or using crewed rovers in a robotic mode when not crewed. This is all to the good and is consistent with our recommendation in *The Scientific Context for the Exploration of the Moon* for development on an integrated human/robotic program. It thus seems logical that a similar approach would apply to Mars for which today we can conduct only robotic exploration.

What is the relationship of the Mars Exploration Program (MEP) to eventual human exploration? It provides, or can provide, two critical contributions. First, science. As is the case with the Moon, science will be a major activity of human exploration of Mars as is noted in the recent report of the Human Exploration of Mars Science Working Group. The MEP of the last decade has been a remarkable demonstration of how rapidly and productively science progresses when there is a strategically guided, methodical, scientifically focused, superbly engineered program. In accord with this, the *Appropriations Act of 2008* makes clear the Congressional intent that there continues to be a strong MEP with missions at every Mars opportunity. Such is apparently not to be. Testimony at the March 13, 2008 hearing of this committee addressed the major cutting of the MEP in the President's proposed 2009 budget and the damage that will accrue to the MEP. While adding my congratulations to Dr. Alan Stern for doing much to improve the overall status of space science, I do not believe that the cuts to the MEP are either warranted or acceptable. I come to that conclusion based on the observation that the MEP is arguably NASA's most successful robotic exploration program in terms of continued, step-wise public-engaging exploration (I note the difference between a program and individual projects such as Hubble and Cassini). It has taken a decade of Mars missions to develop the engineering and scientific communities able to both implement and understand how to explore Mars. That capability can be lost in just a couple of years. The "case study" of the potential damage can be readily seen as NASA is now working hard and paying the price to recreate an engineering workforce capable of developing the Ares vehicles, Orion and Altair. The new NASA Lunar Science Institute was formed partly in order to help recreate a community of lunar scientists.

There is further a direct link between the MEP and the needs of the VSE. We need to keep Mars in the public eye as an ongoing indication of the import of Mars, regardless of the VSE; the public is having a difficult time understanding where the return to the Moon fits in. Mars, along with Earth, is a special planet, not one that should be subject to equipartition of attention in the solar system. In the MEP, and supported by Dr. Stern, is a Mars Sample Return (MSR) mission envisioned towards the end of the next decade. Adequate funding for that is tenuous as you heard on March 13. A sample return from Mars will have incredible science value. Moreover, it will provide absolutely essential precursor information for eventual human exploration. Specifically, we must understand the precise nature of the highly oxidizing Martian soil, will it be toxic to humans and, if so, how does one counter that? What is the nature of the dust particles in an engineering sense. Just as dust is a major concern on the Moon, it is of equal or greater concern on Mars (with active dust storms) and one must have returned sample to adequately treat the issues. One might argue that human exploration of Mars is a long way off, so what's the rush? My response is that the sooner we know and deal with what might be real impediments to human exploration of Mars, the better. Waiting to find out until 2030 or so would be irresponsible given the likelihood that a significant technology development may be required to deal with the results (note that several years ago there was active participation of ESMD in the MEP but was stopped due to budget issues). Lastly, an MSR mission will be proof-of-concept of a Mars round-trip, a not inconsequential demonstration. Many will be the "Oh my goodness" aspects that will need to be considered before we commit to the human adventure.

International Cooperation: Opportunities and Challenges

The final topic you asked me to address relates to the potential opportunities and challenges of international cooperation for human exploration beyond low-Earth orbit and what things might NASA and Congress do now to enhance the potential. The opportunities are in a sense obvious: we cannot afford the exploration we'd like to implement; without significant international contributions the architecture is moot and must be scaled back or stretched out to the point of marginal value for the investment. The latter can force one into the approach of "go as you pay" which is deceptively attractive. There is, however, an ugly potential downside of "go as you pay" in that if there is not enough "pay," the largest budget increment goes to sustaining the infrastructure on Earth. The drawn-out "level-funding" development of the ISS gives some hint of that impact.

Many of the world's space faring nations have developed sufficiently in skill and desire that we should look to them as desirable partners for their own sake and not simply as a source of funding to solve our budget shortfalls after we have announced "Our Vision." Bringing potential partners in early, in the concept formulation phase where they contribute to structuring the basic approach strikes me as the right way to approach international cooperation. That is indeed the way NASA is now approaching the possible international participation in a Mars sample return mission (the recent budget cuts in the MEP do not provide confidence to potential partners that we are serious in our commitment). The Global Exploration Strategy Framework for Cooperation certainly contains a basis for building to eventual closer collaboration.

As we develop more and more collaborative programs, today's trend, it is likely that we shall have to develop a degree of trust that goes beyond what we are historically comfortable with. It is always good if collaborations are not on what is called the "critical path" in which the failure of one party to produce sinks the ship. This becomes more important the larger the program and its collaboration dependency such as in the VSE or MSR. While there are few guarantees for these ventures, having overt, consistent political support from the Congress and Administration can substantially enhance the stability and probability of success. That kind of support was a stabilizing element of the cooperation with the Soviet Union (later Russia) in the Apollo Soyuz Test Project and ISS program.

The politically motivated and largely successful historic cooperation with the Soviet Union naturally raises the question of China, a country clearly aspiring to emulate much of what we do or have done. It is worth examining and questioning whether there is a comparable role with China to what we did with the Soviet Union at the height of the Cold War—recognizing that we are absent much of the

Cold War rhetoric and threats. However, there is obviously an embedded political issue regarding military implications and I leave that for others to wrestle with.

There does remain a thorn in the side of international cooperation and that is the ITAR regulations. While few of us would argue that ITAR does not serve a good purpose in preventing a damaging transfer of technology, the restrictions seem at times to be excessive and unnecessarily make it more difficult to obtain the ease of dialogue necessary for effective cooperation and on occasion lead to a vocal negative response from potential partners. Congressional support for assessing and appropriately easing the restrictions would be welcome.

Mr. Chairman and Subcommittee Members, you have my appreciation for the opportunity to testify today. I hope that my comments are taken as an attempt to contribute to improving the long-term outlook for the NASA space programs in an extremely challenging budgetary and technical environment.

Chairman UDALL. Dr. Thornton.

STATEMENT OF DR. KATHRYN C. THORNTON, PROFESSOR AND ASSOCIATE DEAN, SCHOOL OF ENGINEERING AND APPLIED SCIENCES, UNIVERSITY OF VIRGINIA

Dr. THORNTON. Mr. Chairman, thank you for inviting me to be here today. My name is Kathryn Thornton. I am a Professor at the University of Virginia, but I appear here today not in my faculty role but as an organizer and co-chair of an independent workshop entitled Examining the Vision, Balancing Exploration and Science that was held last February at Stanford University. The workshop was co-hosted by Stanford University Department of Aeronautics and Astronautics and the Planetary Society. Other organizers were co-chair Scott Hubbard from Stanford University, Lou Friedman of The Planetary Society, and Wes Huntress of the Carnegie Institution of Washington.

The intent of the workshop was to critically examine the current implementation of the *Vision for Space Exploration* as announced by President Bush in January 2004. The Vision as originally put forth was rich in scientific goals aimed at finding life elsewhere in the universe pointed toward Mars as the ultimate target for human exploration and couched exploration of the Moon in those terms. Four years later, implementation of the vision has focused on a small subset of the original concepts: finishing the International Space Station for our international partners, retiring the Space Shuttle by 2010, developing new launch vehicles and a new crew vehicle, and the Moon as the near-term goal of human exploration.

Much of the originally planned funding for the human exploration mandates has not materialized and instead has come from science, aeronautics, and technology.

With these concerns as the motivation, the workshop was planned as a two-day, behind-closed-doors discussion of the goals and implementation of the Presidential directive, and the issue of balance between exploration and science. Organizers sought to bring together scientists, astronauts, engineers, policy analysts, and industry executives in a single conversation where insights across traditional boundaries could occur. Invitations were extended to individuals whom the organizers felt would bring great diversity of thought, as well as expertise. Each participant was invited to take off his or her corporate, institutional or advocate hat, and engage in discussion that will help this nation have the best possible space exploration program. To the extent that the outcome might be critical of current plans, progress, or goals, criticism was intended to be constructive and consistent with strong support for space exploration. As expected, lively discussions ensued.

There was some doubt that fifty individuals, selected specifically for their differing specialties and divergent views, could reach a consensus on the goals and directions for America's space exploration program over the course of a two-day workshop. Therefore there was no predetermined workshop report or product, but rather the expectation that these discussion would lead to further study and output in some form. Nevertheless, workshop participants did reach consensus on four substantive statements which in essence endorse the Vision as announced in 2004. Those statements are listed in my written testimony as well as in the workshop joint communiqué.

I would like to expand on the workshop consensus from my own perspective. It is time for humans to go beyond low-Earth orbit. To be sure, the ISS must be completed in order to fulfill obligations to our international partners, but in the longer term the Space Shuttle and ISS serve to anchor humans in lower-Earth orbit, and orbiting the Earth, as thrilling as it is, is not exploring space. This nation must move forward with the development of a space transportation system that will do more than just orbit the Earth, but will enable humans to explore in space.

Although Mars and beyond as the goal of human exploration is a consensus of workshop participants, the question of intermediate steps was debated at length with no overall agreement. A stepping stone approach to Mars might include sorties to the Moon, the Sun-Earth Lagrange points, near-Earth asteroids, and the Martian moons. The important point is that each of the stepping stones, whichever they may be, should advance the science and technology needed for the next, more ambitious objective and the eventual human exploration of Mars, and none should be considered as permanent outposts that would again anchor us in place for decades.

Exploration should be goal driven, not schedule driven. Practical engineering for meeting exploration milestones is bound by three major constraints: budget, schedule, and requirements. If you change one of these three, the other two must change accordingly. Particularly if the budget is over-constrained, either schedule or requirements must give. It is important to remain focused on the goal, not the schedule, and proceed as efficiently and safely as technology and budget will allow.

Sustained human exploration requires international collaboration. We can debate the value of science objectives and exploration goals, but the value of international cooperation in space ventures over the last decade cannot be challenged. Inviting meaningful international participation in the exploration architecture may reduce cost, accelerate the timelines, provide additional capability, bring a measure of stability through numerous budget cycles and administrations, while engaging rivals and allies in a shared commitment to extend the boundaries of humankind into new domains.

In summary, it is time to go beyond LEO with humans as explorers. To do so, we must have a space transportation system that will enable humans to travel to the Moon, Mars and beyond; without it any debate of destinations for human exploration is pointless. Finally, with the goal clearly in focus, budgets and schedules must be balanced for an affordable, sustainable and successful space exploration program.

Mr. Chairman, I thank you and the Subcommittee for your staunch support of the Space Exploration Program and the opportunity to express my views today, and I would be pleased to answer any questions.

[The prepared statement of Dr. Thornton follows:]

PREPARED STATEMENT OF KATHRYN C. THORNTON

Chairman Udall, Ranking Member Feeney, and Members of the Subcommittee, thank you for inviting me to appear before you today. My name is Kathryn Thornton and I am a Professor and Associate Dean in the School of Engineering and Applied Science at the University of Virginia. I appear here this morning not in my faculty role but as an organizer and co-chair of an independent workshop entitled *Examining the Vision: Balancing Exploration and Science* held last February at Stanford University. The workshop was co-hosted by Stanford University Department of Aeronautics and Astronautics, and The Planetary Society. Other organizers were Co-Chair Professor G. Scott Hubbard from Stanford University, Dr. Louis Friedman of The Planetary Society, and Dr. Wesley T. Huntress, Jr., of the Carnegie Institution of Washington. The post-workshop joint communiqué and a partial list of participants are attached.

The intent of the workshop was to critically examine the current implementation of the *Vision for Space Exploration* as announced by President Bush in January 2004, especially to help prepare for a new Administration's consideration of its broad space program goals and plans. The *Vision for Space Exploration* in its original plan was a major redirection of the human space flight program with an accompanying emphasis on scientific exploration. Whatever changes might be made in its implementation in the next Administration, we wanted to identify, highlight and support the best parts of the current concept. Our goal was to create a report intended to be useful in the next stage of policy planning, and potentially to define follow-on studies of the issues.

The *Vision for Space Exploration* provided specific targets, defined human and robotic exploration objectives and set timetables. The Vision as originally put forth was rich in scientific goals aimed at finding life elsewhere in the Universe. In addition, the Vision continually pointed toward Mars as the ultimate target for human exploration and couched exploration of the Moon in those terms. Four years later, implementation of the Vision has focused on a small subset of the original concept: finishing the International Space Station (ISS) for international partners, retiring the Space Shuttle by 2010 and developing new launch vehicles (Ares I and V) and a new crew vehicle (Orion), and the Moon as the near-term goal of human exploration.

With the fixed requirements, fixed schedule and NASA's flat budget, funding to meet the Vision has come from science, aeronautics and technology. Aeronautics has been reduced radically, life sciences have been largely eliminated, the entire cross-cutting technology budget has been redirected, and more than $3B over five years was taken from the space and Earth science budget. Much of the originally planned funding for the human exploration mandates has not materialized, while the cost of returning the Space Shuttle to flight and its impeding retirement has risen.

With these concerns as the motivation, the workshop was planned as a two-day, behind-closed-doors discussion of the goals and implementation of the Presidential directive, and the issue of balance between exploration and science. Organizers sought to bring together scientists, astronauts, engineers, policy analysts, and industry executives in a single conversation where insights across traditional boundaries could occur.

The discussions were organized around the following topics:

1. *Scientific Exploration of the Universe,* in particular the role of a Mars Sample Return mission as a major milestone in scientific and robotic exploration as well as a precursor for human exploration.
2. *The Earth Science and Climate Change:* What should the U.S. be doing to provide policy-makers with the best available information.
3. *Access to Low-Earth Orbit (LEO) and Beyond:* Plans for and capabilities of the Constellation system
4. *The Role of Lunar Exploration* in the human exploration strategy
5. *Human Missions to Mars*

6. *Alternative Destinations for Human Exploration*
7, *Humans and Robots in Exploration:* when is a human the tool of choice for solar system exploration
8. *The Role of the Emerging Entrepreneurial Space Industry*
9. *International Collaboration in Space Exploration*

Invitations were extended to individuals whom the organizers felt would bring great diversity of thought, as well as expertise, on those topics. Each participant was invited to take off his or her corporate, institutional or advocate hat, and engage in discussion that will help this nation have the best possible space exploration program. To the extent that the outcome might be critical of the current plans, progress or goals, criticism was intended to be constructive and consistent with strong support for space exploration. As expected, lively discussions ensued.

Pre-workshop reporting predicted that the outcome of the workshop would be a repudiation of at least some of major the goals of the Vision. There was some doubt that fifty individuals, selected specifically for their differing specialties and divergent views, could reach a consensus on the goals and directions for America's space exploration program over the course of a two day workshop. Therefore there was no predetermined workshop report or product, but rather the expectation that these discussion would lead to further study and output in some form. Nevertheless, workshop participants did reach consensus on the following statements which in essence endorse the Vision as announced in 2004.

- It is time to go beyond Low Earth Orbit (LEO) with people as explorers. The purpose of sustained human exploration is to go to Mars and beyond. The significance of the Moon and other intermediate destinations is to serve as stepping stones on the path to that goal.
- Human space exploration is undertaken to serve national and international interests. It provides important opportunities to advance science, but science is not the primary motivation.
- Sustained human exploration requires enhanced international collaboration and offers the United States an opportunity for global leadership.
- NASA has not received the budget increases to support the mandated human exploration program as well as other vital parts of the NASA portfolio, including space science, aeronautics, technology requirements, and especially Earth observations, given the urgency of global climate change.

These statements represent consensus among all workshop participants. I would like to expand on them from my own perspective.

It is time for humans to go beyond low-Earth orbit. The post-Apollo space program traded exploration for utilization; exploration on the Moon was exchanged for the prospect of a permanent laboratory, factory, and satellite repair station orbiting within a few hundred miles of the Earth's surface. The resulting quest for a permanent presence and routine access to space resulted in the Space Shuttle and later in the International Space Station (ISS). While both are remarkable technological achievements, neither has quite lived up to its promise, and just as the Space Shuttle today bears only a slight resemblance to early concepts for a fully reusable spacecraft, the ISS we have now is not the station that was envisioned more than two decades ago. To be sure, the ISS must be completed in order to fulfill obligations to our international partners. But in the longer-term the Space Shuttle and the ISS serve to anchor humans in low-Earth orbit, and orbiting the Earth, as thrilling as it is, is not exploring space. This nation must move forward with the development of a space transportation system that will do more than just orbit the Earth, but will enable humans to explore in space.

Mars and beyond is the goal of human exploration. Although "Mars and beyond" as the goal is a consensus of workshop participants, the question of intermediate steps was debated at length without overall agreement. A stepping stone approach to Mars might include some or all of the following intermediate steps: sorties to the Moon and the Sun-Earth Lagrange points (L2) as the first step out of LEO; longer missions of perhaps a year's duration to a near-Earth asteroid as the first step out of the Earth's gravity well; and expeditions to the Martian moons, Phobos and Deimos, which would be of similar duration to Mars missions but without the need for complex and risky landing and launch systems. The important point is that each of the stepping stones, whichever they may be, should advance the science and technology needed for the next, more ambitious objective and for the eventual human exploration of Mars, and none should be considered as permanent outposts that would again anchor us in place for decades.

Exploration should be goal driven, not schedule driven. The exploration goal has been repeatedly found to be the basis of public excitement and interest in the space program. In the aftermath of the tragic loss of *Columbia* and her crew, this was forcefully reasserted in the discussions of why human space flight is worth the cost and the risk. Indeed it was in that aftermath that the *Vision for Space Exploration* was born. Exploration is open-ended, it has no limits. But it has interim objectives and those also should be publicly engaging and seen as milestones on a longer road. Practical engineering for meeting milestones is bound by three major constraints: budget, schedule and requirements. If you change one of these three, the other two must change accordingly. Particularly if the budget is over-constrained, either schedule or requirements must give—and that is what is happening today. As a result, the "gap years" in which there will be no US human space launch capability stretch to or beyond the middle of the next decade. At the same time human missions to the Moon by the year 2020, as specified in the Vision, are exceedingly unlikely. I strongly believe the goals of the Vision are valid, but recognize that budget difficulties will remain. It is important to remain focused on the goals, not the schedule, and proceed as efficiently and safely as technology and budget will allow.

Science is enabled by human exploration, but is not the goal of exploration. To be sure, there are compelling science objectives at each of the intermediate destinations en route to Mars, and important scientific questions that must be answered before humans can venture beyond LEO. But the motivations for science and human exploration are different, even as they are synergistic. Science seeks to answer questions of the origin of the universe and of ourselves, and the processes that govern nature. Motivation for human exploration is largely derived from innate human characteristics such as curiosity, imagination and the desire not just to understand but to experience, the drive to compete and more recently the need to cooperate. Geopolitical influences shape our exploration goals as much now as they did in the 1960s.

One of the questions posed in the workshop was, "When is a human the tool of choice for solar system exploration," to which one participant responded, "as soon as possible when exploration has transitioned from *reconnaissance to meaning.*" Humans solve puzzles and find meaning in data, albeit at a higher cost than our robotic surrogates. We could debate the relative value of humans versus robots at great length but, in fact, we would be missing the point. Humans are explorers. Whether deep under the ocean, on the frigid plateaus of Antarctica, or above the atmosphere, humans are programmed to indulge our unquenchable thirst for knowledge—not only scientific data but human experiences. We are unwilling to surrender those domains solely to robotic surrogates and forego the human experience of adventure and discovery.

We must balance science and exploration, and manage expectations as we move forward. NASA's portfolio includes Earth and space science, aeronautics, and technology as well as exploration, and a healthy balance must be maintained among the sciences, and between science and exploration. Science is of enormous benefit and interest to the public and to our future generations—the inspiration derived from Hubble and the Mars rovers are but two examples, the 2006 Nobel Prize in physics for work that was based on measurements from COBE is yet another. The science budget should not be used to compensate for the underfunding of the Vision goals.

Furthermore, science programs are not just budget lines, they are people. They cannot be turned on and off without consequence. As NASA's aging workforce reaches retirement, how are we going to attract the next generation of scientists and engineers who will continue exploring the universe? I believe we must pull rather than push; pull students into science and engineering with the promise of interesting work and a fulfilling career. What more powerful pull can there be than the opportunity to explore the universe? When budgets are redirected and the very programs that attracted young scientists are summarily terminated, they are forced to retool, retrain and reeducate themselves for other careers. They are in all likelihood lost to the NASA workforce forever and we are all poorer for it.

The entire field of microgravity science was based on the expectation of a space station for long-term experimentation. Drop towers, zero-G flights and even two week flights on the Space Shuttle were just warms up for the permanent laboratory in space. Young scientists built their careers on that promise. Even as ISS grew in orbit, opportunities for its use as a world class laboratory for microgravity science were shrinking. Microgravity science, born in the 1980s, was effectively killed in 2004.

As we execute the *Vision for Space Exploration,* it is important to be realistic about the goals, funding and timeline for science and exploration. Should we cast a net widely within the science community to find all possibilities for exploration and research that could be accomplished on the Moon, and therefore solicit the broadest possible support within the science communities for a lunar program, or should we focus from the outset on science objectives that support the next step in the overall exploration strategy? Let's not repeat the microgravity science experience on the Moon.

Sustained human exploration requires international collaboration. From the very beginning, human exploration has been driven by geopolitical factors, in the U.S. as well as in the Soviet Union then and in Russia now. As we make plans to explore beyond Earth, it is appropriate that those political forces have led to cooperation rather than competition.

The U.S. is the unquestioned leader in space exploration, a position that we are unwilling relinquish. International collaborative exploration initiatives offer the United States an opportunity to maintain global leadership in a cooperative environment. Collaboration with international partners provides opportunities for countries who may be competitors in global political or economic arenas to work together to increase human knowledge and promote peaceful utilization of the solar system.

The road to Mars will be a very long one, and any architecture must survive many one-year budget cycles and four-year administrations. After several near-death experiences, the ISS is still alive and will be completed because of our international commitments. The overriding importance of multi-national cooperation justifies the risk and cost of continuing the Space Shuttle program long enough to satisfy our obligations.

We can debate the value of science objectives or exploration goals, but the value of international cooperation in space ventures over the past decade cannot be challenged. Inviting meaningful international participation in the exploration architecture may reduce cost, accelerate the timeline, provide additional capability, bring a measure of stability through numerous budget cycles and administrations, while engaging rivals and allies in a shared commitment to extend the boundaries of humankind into new domains.

The role of entrepreneurial space ventures should be to help NASA get out of the business of routine transportation to LEO for cargo and crews as soon as practical. Non-government entities have transported cargo to space for decades, but only NASA and the Russian Space Agency transport humans to the ISS. As we have seen over the past two decades, our space transportation system has at times left us stuck on the ground. U.S. flights were suspended for almost three years after *Challenger,* more than two years after the *Columbia* accident and will be suspended for some number of years after the retirement of the Space Shuttle in 2010. Shorter down-times of months to one year have resulted from problems with helium leaks and external tank insulation shedding. As long as NASA is the owner, operator and sole customer of transportation services to LEO in this country, there is no competition for services and limited access to space.

The emerging entrepreneurial space industry projects growing demand for access to space by foreign governments who want to get into the space business, from multinational corporations and from tourists. NASA is investing in commercial space transportation services through the Commercial Orbital Transportation Services project (COTS) for cargo to the ISS, and eventually crew transport as well. Bigelow Aerospace and Lockheed Martin Commercial Launch Services are engaged in discussions on the Atlas 5 as the launch vehicle to provide crew and cargo transportation services to a Bigelow-built space complex in the near-term.

As NASA refocuses on exploration, commercial ventures that will replace NASA as the sole U.S. human space transportation system should be encouraged and incentivized by NASA and by Congress. Assurances that NASA will become a customer, not a competitor, in LEO would strengthen the business case for companies who are investing in this venture.

NASA has not received budget increases to support the mandates of the Vision for Space Exploration and the other elements of its portfolio even in the most optimistic scenarios. Each year since 2004 when the Vision was announced, the NASA budget has fallen short of that required to achieve the mandated exploration goals and milestones. Science, aeronautics and technology have suffered severely to compensate for the shortfall. Costs associated with the Space Shuttle retirement are not budgeted. The gap between Space Shuttle retirement and Orion crew exploration vehicle (CEV) initial operational capability is widening. In short, there is a mismatch between aspirations and appropriations that no amount of spin can disguise.

Faced with inadequate budgets, the other two elements of the budget—schedule—requirements triad must be reassessed. Again I urge that we focus on the goals of the Vision, not the schedule, and proceed in the most efficient, cost-effective and safe manner possible.

Is the Constellation system a vehicle for science as well as human exploration? I was asked to address potential advantages of using Constellation systems for science exploration missions, a question not considered at the workshop, but is the subject of an on-going NRC study. Constellation systems being designed primarily to achieve human exploration goals would enable larger, heavier and more capable spacecraft as well as human servicing options to meet science objectives that are synergistic with or independent of Vision goals. The Ares V launch vehicle, as envisioned, would offer significant increases in payload volume and payload mass *at a significantly higher cost* when compared with Delta and Atlas families of launch vehicles available today. In general, the advantages of launching "flagship"-class science missions on an Ares V are:

- Larger diameter payload fairing would allow larger optics (mirrors) for a significant improvement in high resolution imaging. The proposed Ares V 10-m (8.8-m usable) diameter payload fairing is roughly twice the diameter of the largest fairings available on the Atlas 5 or Delta IV (collectively referred to as EELV).
- Larger payload volume could lower complexity and mission risk by reducing the number of deployment mechanisms required to fit a spacecraft into a EELV-sized payload fairing. Larger payload volume may also reduce or eliminate the need for in-space robotic assembly of larger spacecraft.
- Larger payload mass would allow for redundant components for longer service life, and additional instruments, propulsion elements and propellant. Mission concepts that require multiple EELV launches could be consolidated into a single Ares V launch with integration of as much hardware as possible prior to launch.
- Future derivatives of the Orion crew capsule that include provisions for extra vehicular activities (EVA) could enable astronauts to assemble, service, repair and modernize science spacecraft outside of LEO, for instance at Sun-Earth L2 which is the proposed location for several large astronomical instruments and a potential stepping stone destination on the path to Mars. In the same way that the Hubble Space Telescope has been rejuvenated four times over its 18-year life, human servicing capability at L2 could greatly extend the useful life of spacecraft and instruments.

I am not aware of any reliable cost estimates for an Ares V launch, but it seems reasonable to assume that the incremental cost of a launch vehicle capable of putting 140 MT into LEO would be several times the cost of a 25 MT-capable launcher. Similarly, the cost of a science payload that requires such lift capability or would take advantage of the payload volume of the Ares V would be considerably more costly than "flagship" missions currently being developed for launch on EELV.

If Ares V launch vehicles were available for science missions in 2025 or later, there would undoubtedly be a number of mission concepts that would enable a qualitative new approach to the important scientific questions in fields such as astronomy, astrophysics, heliophysics, Earth science, or planetary science to name a few. However, the greatly increased payload capability promised by Ares V would also result in more costly science payloads and significantly more expensive launch vehicles. One billion dollar "flagship" class missions could well be superseded by $5B to $10B "super flagship" missions.

Unless the space science budget grows as the launcher capability grows, science missions that take full advantage of the capabilities of the Ares V cannot reasonably be flown on a routine basis.

Two post-workshop follow-on activities are in progress at this time. Workshop organizers are in the process of writing a detailed summary of the presentations and discussions that led to the consensus statements. Not seeking a consensus of all workshop participants, the intention is to represent the nuances of the discussions and various points of view, and to provide recommendations for the next Administration's consideration. The Planetary Society, a co-host of the workshop, is conducting a series of "town hall meetings" at several cities around the country to gain an understanding of public opinion on topics addressed at the workshop. The Society will use the results of these discussions to produce a roadmap for space exploration for the next Administration and Congress. The roadmap will cover robotic missions of exploration, human space flight, international activities, and public interests. The first of the town hall meetings was held on March 29 in Brookline, MA.

In summary, it is time to go beyond LEO with humans as explorers. To do so, we must have a space transportation system that will enable humans to travel to the Moon, Mars and beyond; without it any debate of destinations and goals for human space exploration is pointless. We will explore with multinational partners to serve our own national and international interests, as well as to advance knowledge. With the goals clearly in focus, budgets and schedules must be balanced for an affordable, sustainable and successful space exploration program.

Mr. Chairman, I thank you and the Committee for your staunch support of the space exploration program and the opportunity to express my views today. I would be happy to answer any questions.

[THE JOINT COMMUNIQUE ISSUED REPRESENTING THE CONSENSUS VIEW OF THE WORKSHOP]

Space Experts Say: Restore Funding and Enhance International Outreach to Put Humans on Mars While Sustaining NASA's Science Mission

THE PLANETARY SOCIETY

STANFORD, CA—NASA's program for human exploration must lead to Mars and beyond, and achieving that goal will require future presidents to embrace international collaboration and to fund NASA at a level that will also sustain its vital science programs, stated the organizers of a space exploration workshop today after intensive discussions Feb 12 and 13.

"This workshop achieved a consensus that NASA's resources have not been commensurate with its mandated missions of exploration and science," said G. Scott Hubbard, former Director of NASA's Ames Research Laboratory in Mountain View, California, and a consulting professor of Aeronautics and Astronautics at Stanford.

"The next administration should make the human space flight goal an international venture focused on Mars—both to bring in more public support and to sustain the program politically," added Louis Friedman, Executive Director of The Planetary Society in Pasadena, California.

Friedman; Hubbard; Kathryn Thornton, a former astronaut and current Professor in the School of Engineering and Applied Science at the University of Virginia; and Wesley T. Huntress, Geophysical Laboratory, Carnegie Institution of Washington co-organized the workshop.

The Workshop Joint Communiqué

In particular the attendees agreed to the following set of six statements:

- It is time to go beyond LEO with people as explorers. The purpose of sustained human exploration is to go to Mars and beyond. The significance of the Moon and other intermediate destinations is to serve as stepping stones on the path to that goal.
- Bringing together scientists, astronauts, engineers, policy analysts, and industry executives in a single conversation created an environment where insights across traditional boundaries occurred.
- Human space exploration is undertaken to serve national and international interests. It provides important opportunities to advance science, but science is not the primary motivation.
- Sustained human exploration requires enhanced international collaboration and offers the United States an opportunity for global leadership.
- NASA has not received the budget increases to support the mandated human exploration program as well as other vital parts of the NASA portfolio, including space science, aeronautics, technology requirements, and especially Earth observations, given the urgency of global climate change.
- Additional recommendations will be provided by the organizers and participants in this workshop.

About the workshop

The two-day workshop, co-sponsored by The Planetary Society and the Department of Aeronautics and Astronautics at Stanford University, was an invitation-only meeting of 45 space exploration experts, including top scientists, former NASA officials, and leading aerospace industry executives. Eight of the attendees were former astronauts (for the agenda and attendees see *http://soe.stanford.edu/research/evlist.html* or *http://www.planetary.org/programs/projects/space_advocacy/examining_the_vision.pdf*).

The group gathered privately to engage in a frank, wide-ranging discussion of the Bush Administration's *Vision for Space Exploration* and the policy options facing the new administration that will take office in January 2009.

Topics discussed by the attendees in a series of 90-minute panels included scientific exploration; Earth science and climate change; lunar exploration; sending humans to Mars; alternate human exploration destinations; humans versus robots for exploration; vehicles for accessing low-Earth orbits and beyond; emerging entrepreneurial space activity; and international collaboration.

"The Space Shuttle has been an incredible workhorse in low-Earth orbit for more than 25 years, but now it is time for humans to move out into the solar system," Thornton said.

Examining the Vision Workshop:

http://www.planetary.org/programs/projects/space_advocacy/2008_workshop.html

Examining the Vision: Balancing Science and Exploration

February 12-13, 2008

Workshop Attendees (partial list)

Buzz Aldrin	StarBuzz Enterprises LLC
Jim Bell	Cornell University
Ron Birk	Northrop-Grumman Corp
David Black	University Space Research Association (Ret.)
Jim Cantrell	Strategic Space
Brian Cantwell	Stanford University
Bill Clancey	Institute for Human and Machine Cognition
Nancy Colleton	Institute for Global Environmental Strategies
Pau Eckertl	Boeing
Bob Farquhar	National Air and Space Museum
Chris Field	Stanford University
Len Fisk	University of Michigan
Peter Friedland	Technology Consultant
Louis Friedman	The Planetary Society
Lori Garver	Capital Space
Noel Hinners	Aerospace Consultant
Scott Horowitz	Doc's Aerospace
Scott Hubbard	Stanford University
Russ Kerschman	NASA Ames Research Center
John M Klineberg.	Consultant
Pascal Lee	Mars Institute
Lon Levin	SkySeven Ventures
John Logsdon	George Washington University
Stephen Mackwell	University Space Research Association LPI
Mike McCulley	United Space Alliance
Chris McKay	Ames Research Center
Brian K. Muirhead	JPL
Tom Pierson	CEO, SETI Institute
Jeff Plescia	Applied Physics Lab / Johns Hopkins University
Charlie Precourt	ATK Launch Systems
Harold Reitsma	Ball Aerospace
Ken Reightler	Lockheed Martin
Joe Rothenberg	Universal Space Network
Steve Schneider	Stanford University
Russell L. Schweickart	B612 Foundation
Marijean Seelbach	Lockheed Martin Space Systems Company
Mark Sirangelo	Space Dev
Doug Stetson	Jet Propulsion Laboratory
Kathy Thornton	University of Virginia
Neil De Grasse Tyson	Hayden Planetarium
Jim Voss	Space Dev

BIOGRAPHY FOR KATHRYN C. THORNTON

Kathryn C. Thornton is a Professor at the University of Virginia in the School of Engineering and Applied Science in the Department of Science, Technology and Society and Associate Dean for Graduate Programs in Engineering. She earned her Masters of Science and Ph.D. in physics from the University of Virginia in 1977 and 1979, respectively, and a Bachelor's of Science in physics from Auburn University in 1974. From 1984 to 1996, Thornton was a NASA astronaut and is a veteran of four Space Shuttle missions. She has logged over 975 hours in space, including more than 21 hours of extra vehicular activity (EVA).

Thornton was a mission specialist on the crew of STS–33 which launched at night from Kennedy Space Center, Florida, in 1989 aboard the Space Shuttle Discovery. The mission carried Department of Defense payloads and other secondary payloads. In 1992 on her second flight, Thornton served on the crew of STS–49 on board the maiden flight of the new Space Shuttle Endeavour. During the mission the crew performed four EVAs (space walks) to retrieve, repair and deploy the International Telecommunications Satellite (INTELSAT), and to demonstrate and evaluate numerous EVA tasks to be used for the assembly of Space Station Freedom. The following year Thornton was again a mission specialist EVA crew member aboard the Space Shuttle Endeavour on the STS–61 Hubble Space Telescope (HST) servicing and repair mission. During the 11-day flight, the HST was captured and restored to full capacity through a five space walks by four astronauts. On her final mission in 1995, Thornton served aboard Space Shuttle *Columbia* on STS–73, as the payload commander of the second United States Microgravity Laboratory mission. The mission focused on materials science, biotechnology, combustion science, the physics of fluids, and other scientific experiments housed in the pressurized Spacelab module.

Since leaving NASA, Thornton has served on several review committees and task groups, including the NASA Mars Program Independent Assessment Team and the Return to Flight Task Group which evaluated NASA's work in meeting goals set by the *Columbia* Accident Investigation Board prior to resumption of Space Shuttle flights. Dr. Thornton also served on the NRC Aeronautics and Space Engineering Board, the Committee for Technological Literacy, and the Committee on Meeting the Workforce Needs for the National Vision for Space Exploration, and is currently a member of an NRC Committee assessing science opportunities enabled by NASA's Constellation system. She also is a co-author on Pearson Scott Foresman's K–6 grade Science program. Prior to becoming an astronaut, Thornton was employed as a physicist at the U.S. Army Foreign Science and Technology Center in Charlottesville, VA.

Dr. Thornton is the recipient of numerous awards including NASA Space Flight Medals, the Explorer Club Lowell Thomas Award, the University of Virginia Distinguished Alumna Award, the Freedom Foundation Freedom Spirit Award, and the National Intelligence Medal of Achievement.

DISCUSSION

Chairman UDALL. Thank you, Dr. Thornton. Speaking as a Member of this committee, I want to express my appreciation for the Stanford workshop, and you undertook that effort with the same spirit of risk that you undertook the four missions to Shuttle as an astronaut. So thank you.

I know the members of the panel here noted with interest your term lively to describe the discussions you had. We have a lot of lively discussions here in the United States House of Representatives as well.

At this point, we will open our first round of questions. The Chair recognizes himself for five minutes, and I would like to start with Dr. Gilbrech, focusing on Constellation and particularly the status of the CEV and the CLV projects. First, are there any Constellation-related contract modifications in process or being contemplated that would alter, add tasks, or change performance requirements; and if so, what are they, why are they needed, and what is the cost impact of the changes? Easy set of questions, I know.

Dr. GILBRECH. Yes, sir. Well, as you are aware, we have gotten all the stack under contract. We finished all the Ares I contracts by the end of 2007. We have been working with Lockheed-Martin in the Orion arena. We had done one contract mod in April of last year that accounted for several of the changes that were as a result of things like moving the date from 2011 to 2013. Some of the launch abort system tasks that we had added, so we have made that contract mod and that value went from $3.9 billion to $4.3 billion. Right now we are in the process of going to PDR, so we have got our best take on the requirements that we have and we are negotiating with Lockheed-Martin. We will inform this committee as soon as we have those negotiations firm. Those are all negotiated terms that are within the reserves of the project, so we don't expect that there should be any challenges presented by that and we will be happy to report those.

Chairman UDALL. Thank you, and the Committee looks forward to those ongoing reports and any additional information you might want to add to fill out the question I asked.

Ms. Chaplain, if I could turn to you, what do you see as the greatest risks to the successful development of the Constellation system and are you satisfied that NASA has developed a sufficiently detailed risk management process to help monitor and mitigate risks for Ares and Orion?

Ms. CHAPLAIN. We haven't assessed their risk management process in and of itself, but we have certainly relied on it to help us identify the risk areas, and it has been very useful in that regard. So I think the technical and requirements risks are very well-understood. When it comes to developing risk mitigation strategies, the important thing is to see how they are tied to dollars and schedule; and I believe that is what NASA has been doing.

In terms of the overall risks we just see going forward, they are pretty much what I mentioned in the testimony at this point. It is making sure requirements are fully defined by the time you hit that preliminary design review and then gaining all the knowledge you need on technology development, especially with the components that are requiring a bit of new work, like the J–2X engine. And going forward, the two things that we will always be looking at are things like funding commitments and making sure they are sustained. Whenever you have disruptions, you have a lot of reverberating effects on a program. So if there are future things like continuing resolutions, we would be looking to see what the subsequent impacts of those things are.

You just mentioned requirements changes or contract changes which are normal at this point in the cycle. What we would look at going further once you have committed to the program, you pass your preliminary design review, what kinds of changes do you make at that point and what kind of consequences do they have on the program.

Chairman UDALL. When you mentioned continuing resolutions, of course, the United States Congress plays a role in getting resolutions up. I appreciate your reminding us of that important responsibility.

If I could turn back to Dr. Gilbrech, do you agree with the GAO's assessment of the risks and uncertainties that remain; and in your opinion, what are the leading risk areas associated with the CEV and the CLV and how do you propose to mitigate them?

Dr. GILBRECH. Yes, sir, Mr. Chairman. We have worked with GAO on their report, and we appreciate the responsibility they have in reporting to Congress. We always want to maintain visibility and transparency so that you are comfortable that we are spending the taxpayers' dollars wisely. So we have worked with them closely on their reports, and we agree with their findings and are implementing their recommendations.

You asked about risks. Probably the biggest risk to me is not really technical, it is the stability that was mentioned in some of the other opening statements, of the program. The funding, ability for us to stay the course and be able to go through administration changes and Congressional cycles and be able to stay on a longer term path. It really does take that long-term commitment to execute a program of this magnitude. This is the first time we have had a new space policy direction in 35 years, and it doesn't turn on a dime. So again, that is kind of my overarching, what keeps me awake at night problem. But if you get down to the second one, technically integration across all the different elements, the Orion, the first stage, the upper stage, the Orion, making sure that everything is properly integrated is one of the other biggest challenges in my mind. We have other technical issues as any new rocket development program will have. Among those we have got some of the thrust oscillation issues that you have been hearing about and I mentioned in my opening statement. To me that is nothing that is alarming, it is nothing that was unexpected. These are the types of things you run across when you start to develop new rockets and try to integrate them, and you get smarter as you try to mature towards PDR. The J–2X was also mentioned. We have taken strides to add extra hardware to the program. We have also—one of the concerns of the GAO was having enough test facilities. We have worked with the Space Shuttle Management Program to not only have the A1 Test Stand down at Stennis which is currently doing J–2X testing, but also to secure the A2 Test Stand to do some more early testing that we know will be challenged to do. We typically know that there are as many as 29 rework cycles in developing a new engine, and so you require an awful lot of testing to do that. But we feel like now we have a robust test program and a test plan, and we are marching forward with that.

Another risk is a launch abort system which is a new system that actually contains three new solid rocket motors. They are small scale but they are new solid rocket development programs. We again have a robust test program to address that. We have been doing some of the early motor firings. We actually just have delivered the Pad Abort-1 Orion Simulator out to Dryden Research Facility to be outfitted with avionics. That will be sent to White Sands Missile Range where we will be doing an actual pad abort test by the end of this calendar year, and we have a series of those abort tests planned to prove out the concepts before we actually fly and put humans on board.

Chairman UDALL. Thank you for that helpful analysis of where we are.

The Chair now recognizes the Ranking Member, Mr. Feeney, from Florida for five minutes.

Mr. FEENEY. Thank you, and I would like to follow up where the Chairman left off. Ms. Chaplain, you have pointed out some of the challenges. We manage the program into the future, you have got an extensive report which we appreciate. Do you agree with Dr. Gilbrech that despite the technical issues and despite the definitional issues that you described that the biggest risk to the program is stability and Congressional and presidential leadership in the coming years?

Ms. CHAPLAIN. I think because it is a very long-term effort, that a commitment is absolutely needed through administrations as well as funding stability. One of the number one things that tends to disrupt programs that we review are funding shifts, stops and starts; and it really hampers what the program managers are trying to do in terms of execution, especially in space efforts where you have a lot of long lead items that you need to purchase.

At the same time, you know, there are other common things that programs tend to face that don't have to deal with funding, and those issues are like requirements, changes, and some technical challenges; and I think those are always going to be present and need to be watched as this program moves forward.

Mr. FEENEY. Some of those you have laid out in your report.

Ms. CHAPLAIN. Yes.

Mr. FEENEY. Would you agree that it is fair to say that while your report is very comprehensive in noting the challenges ahead, that there have been no serious or fatal flaws thus far in advancing toward the program on NASA's part?

Ms. CHAPLAIN. None that we have determined to be a fatal flaw.

Mr. FEENEY. Dr. Gilbrech, while our best scientists have been preparing to take humans beyond low-Earth orbit, you may or may not have noticed that Americans have been involved in a political election year. And one of the potential collateral effects of that is we may in fact have a continuing resolution which Ms. Chaplain—a lot of us on this committee, you know, would like to see something different. But if we have a continuing resolution for 2009 that effectively provides 2008 funding, what does that do for the March 2015 schedule that NASA is trying to obtain?

Dr. GILBRECH. Congressman, we have looked at that, and it depends on the length of the continuing resolution. If it is a part-year resolution, then we do wind up with a 2009 funded level—we get that passed and it wouldn't be as big of an impact. But if we did wind up with another year-long continuing resolution like we did in 2007, our 2008 budget to 2009 would be decreased by about $350 million in exploration; and as we said, our rule of thumb in the program is about $100 million cut——

Mr. FEENEY. A month.

Dr. GILBRECH.—a month, so about four months of scheduled delay on the March 2015.

Mr. FEENEY. Okay. Ms. Chaplain, again, I thought your report was very comprehensive. With respect to Congress' role, how should we take the challenges that you have laid out, and what should Congress be focused on? Should we be focused on definitional issues, milestones, critical decision points, program reviews?

You know, if you were the Chairman and the Ranking Member, what would you be planning to do the next three or four years as oversight? Other than getting funding, which is a given.

Ms. CHAPLAIN. Right. We always focus on several key milestones in a development program where we know that best practice organizations have gained certain pieces of knowledge at that point that makes them know it is okay to move forward. They have the assurance they need that what they are trying to do can be executed well.

The first major milestone is this preliminary design review coming up, and what we like to see at that point is whether new technologies being developed are mature to a point where you can estimate costs and time and whether requirements are stable. So do you know what you are setting out to achieve and do you know that you have the resources to achieve that? And that would be this upcoming preliminary design review.

Then the mid-point of a program is usually the critical design review, and there we really look to see whether design is stable; and the common measure that is used is the number of design drawings that are releasable. And the indicator there, if there is about 90 percent drawings releasable, you have a good assurance that design is stable and you are ready to move forward to the next stages. Then when we get close to production, we look at some production indicators, whether the processes that are going to be used in production are stable or not.

So with those three key gates, there are indicators you can use to see how the program is progressing. In addition to that, we always track things like software growth and whether assumptions about the use of heritage technologies and hardware are still valid in the program. And we also track things like weight growth because in space programs, that tends to be a particular issue if weight just creeps up during the development and if it is not addressed.

Mr. FEENEY. Mr. Chairman, my time has expired. I hope with the indulgence of the Committee, we may have an opportunity for a second round subject to votes. But I would like to point out if I may that Ms. Chaplain's report is very comprehensive. She did state in her testimony that she hopes NASA will continue to be as candid as it has been thus far, and I think we ought to recognize that candor will be important for the GAO, for Congress, and the public; and we do appreciate the candor thus far.

With that, I will yield back.

Chairman UDALL. I thank the Ranking Member, and I also would note that the Ranking Member in his comments alluded to a job that all of us here on the Committee in regards to our presidential—potential presidential nominees, so I am counting on Congressman Feeney to make sure that Senator McCain understands the importance of the Exploration Initiative and I know Congressman Lampson and I and other Members on this side of the aisle will make sure that Senator Obama and Senator Clinton know this not only is important to NASA but it is important to the country's economic future.

Mr. FEENEY. If I can respond just briefly, I want to assure the Chairman that I, along with some great leaders at the Space Coast and around the country really, for space, gave an absolutely brilliant briefing on the importance of the Space Program. Unfortunately, we gave it to Governor Romney who I had supported at the time. But we are in practice.

Chairman UDALL. On that note, it is a great pleasure to recognize the Chairman of the Subcommittee on Energy and Environment, the Member from Texas, Mr. Lampson, for five minutes.

Mr. LAMPSON. Thank you, Mr. Chairman. Mr. Feeney, get ready to make that presentation again as soon as you possibly can.

Dr. Thornton, I think you are certainly right. It is indeed time for humans to go beyond low-Earth orbit. I just hope that those humans are from the United States of America, that we don't lose the commitment that we have been talking about here and let someone else beat us to it. So obviously that is why we are here, and I hope that we can keep our focus and understand what unbelievable returns we have gotten for our standard of living and quality of life and economy and everything else that NASA has given to us because of these dreams that we have achieved—strived to achieve and have indeed achieved, no question.

But Dr. Gilbrech, if you were provided with a significant funding increase to the Constellation Program on the order of a billion or $2 billion, what would you use the money for in specific terms and how much of an impact would the extra funding have?

Dr. GILBRECH. Yes, sir, Congressman and of course we support the President's budget, but if the Congress would enact extra funds, we reported previously in hearings that $1 billion in fiscal year 2009 and $1 billion in fiscal year 2010 would accelerate the initial operating capability at the 65 percent confidence level that we are currently holding back to September 2013, we would simply have the reserves in the year that we need to address the kind of problems that we see that would bring us back into the 2013 timeframe. I personally would also like to look at adding more robust flight test programs. That is something that we can never do enough of, is test what we fly. You want to always fly and learn in the early test programs because all the ground analysis and ground tests never really quite fill in all the gaps that a flight test program does.

Mr. LAMPSON. If United States access to the International Space Station was accelerated by this extra funding, would this have a commensurate affect on a projected human lunar landing date?

Dr. GILBRECH. Right now, we are just in the early formulations for the human lunar return, and as was stated, our current goal is by 2019 is to put boots back on the Moon. So certainly progress in the early stages with the Ares I and the Orion would certainly make that much more—higher confidence and potentially pull that up, but it is a little far in the future for us to put that kind of fidelity to it. I think it would certainly make our 2020 commitment firm, our 2019 target much more achievable and could potentially accelerate that date.

Mr. LAMPSON. Ms. Chaplain, your testimony indicates that NASA's assessment that it could accelerate the Constellation Program's initial operational capability date to 2013 with an additional $2 billion as highly optimistic. You go on to state that given the linear nature of a traditional test-analyze-fix-test cycle, even large funding increases offer no guarantee of program acceleration. Given the difficult situation we find ourselves in with the possibility of a five-year gap, what credible options do we have for closing that gap if we don't add more money to the Constellation Program?

Ms. CHAPLAIN. I think I agree with what Dr. Gilbrech was saying, that the funding could be used to increase your confidence levels of hitting that 2013 rate. It doesn't necessarily mean that it is going to speed up activities that are already laid out on the books because they are already pretty highly compressed, and testing does have to occur in sequence. So I am not doubting that they could have more confidence to the 2013 date. What we meant to say is there is only so much you can do to shrink what is already there for certain aspects of the program. That would be the J–2X engine and the upper stage, that there is—it is highly unlikely that you are going to get those things to come under what schedules they have now. As I understand it, the schedules are sort of laid out to hit the 2013 mark. Extra money would help. You have more confidence in that. Even at a 65 percent confidence level, you still have to recognize that is 35 percent confidence. You might not hit that—you won't hit that date.

Mr. LAMPSON. Dr. Gilbrech, do you agree with Ms. Chaplain's assessment of the feasibility of accelerating the Constellation Program if more money was added? If not, why not? What are your thoughts?

Dr. GILBRECH. I think we are in agreement that the reserves allow us to tackle problems against that aggressive 2013 schedule date, but again, our external commitment is the March 2015 because we know we can sign up and meet that date at the 65 percent. I don't want to get hung up on 65 percent because I really see this as a very achievable architecture. I have worked a lot of programs that have tried to replace the Shuttle, so I have some scars underneath my jacket here. The X–30 program was the Ronald Reagan era of the Orient Express. It was an air breather that was supposed to take us up to orbit, a huge technological challenge and a revolutionary leap in technology. I also worked the X–33, and there again, we were trying to go single stage to orbit. It was a composite vehicle, had a linear aerospike engine which worked beautifully, but unfortunately, the fuel tank technology wound up burying that program.

So we are using a very evolved technology approach here. We are using Shuttle solid-rocket boosters that have a rich flight heritage. We are using upper stage which J–2X engines have their roots in Apollo heritage. So for my mind, the schedule, I have a very high confidence in the 2015 date and if there were additional money, the 65 percent would just buy us additional confidence in the 2013 aggressive date. So I view it more as we have a very evolved, achievable technology path ahead of us than anything I have seen in the past.

Mr. LAMPSON. My time has expired, Mr. Chairman. Thank you.

Chairman UDALL. Mr. Lampson, Dr. Hinners, I couldn't help but note that you mentioned the witness protection program earlier in your remarks. I know of no witnesses coming before this committee that has needed the witness protection program. I do, however, suggest that given what I know about Mr. Lampson's Congressional District and Mr. Rohrabacher's Congressional District, that they may at some point need the witness protection program.

On that note, I did want to recognize the gentleman from California. He is a very engaged and productive and contributing Member of the Committee, Dr. Congressman Rohrabacher from the great State of California. I don't think he is actually a doctor but we treat him as one. Mr. Rohrabacher.

Mr. ROHRABACHER. Yes, thank you very much, Mr. Chairman. Just one note, after you have been here 20 years, the most visible aspect is that from up here, when I got here 20 years ago, the witnesses were all older than I was, and they seem to be younger than I am. And over that 20 years, I have noticed, and I certainly understand and I have heard this before, about the instability of our funding and the effect that it has on a long-term space program and long-term goals. Let me just note that what I perceive is that instability of funding can be traced back to the fact that it is almost impossible for people to prioritize spending. And if we were able to prioritize in the beginning, we would have much more stability. That lack of ability to prioritize is not just on the part of Congress, however, it is also on the part of the space community. So what I would ask you now—and of course, Dr. Martin, of course, who just came for this robust discussion, what areas have been identified as the least justified spending that is going on our space program today? Dr. Thornton, let me start with you. Did anyone identify—see, everyone can talk about what should be plussed up, but no one is willing to talk about what should not be in the budget. So maybe you could help me. Was there any discussion about things that were not justified that we are spending money on today?

Dr. THORNTON. I don't know that I can say there was a discussion of not justified, but I think there was pretty widespread agreement that what has happened on the Space Station has not captured the public's attention. And orbiting the Earth over and over and over again is not capturing or holding the public's attention. What we need to do is have these goals. Maybe Mars is too far into the future.

Mr. ROHRABACHER. And so you're saying your recommendation would be to cut funds for the Space Station Program, is that right?

Dr. THORNTON. Well, I think that we have to finish it for international partners.

Mr. ROHRABACHER. So you want to actually spend more money on it? Okay. Frankly, this is what we got. For the last 20 years, that is what I have identified. Not one witness—I have asked this question a dozen times—has ever been able to tell me what is the least-justified spending. They are always willing to say, well, they all have their own special program. They want to plus up. Does anyone have anything else they want to jump in as well?

Dr. THORNTON. I think I said that we needed to balance expectations and budget. You know, I think that——

Mr. ROHRABACHER. I am not asking for balance, I am asking for what you would like to cut spending on——

Dr. THORNTON. Nothing.

Mr. ROHRABACHER.—and if we could get——

Dr. THORNTON. Nothing.

Mr. ROHRABACHER. Nothing? Okay. Well, that is why we don't have a stable program because no one is willing to say it. Are there any other witnesses willing to tell me where it is the least-justified? Okay. So nothing has changed. Let me just notice, it is not just the responsibility of Members of Congress. It is also the responsibility of you and the rest of the people in the space community to tell us this. Now, all we get is people telling us where we need to spend more. Well, if we want stable spending, we have got to find out where we need to spend less and get some good expertise advice on it so we can set priorities.

One of the things that I have seen that might help us out in terms of making sure that we have the resources available to meet the goals, which of course, people are willing to say we need to spend more money on, is perhaps a initiative that would not cost money, initiatives that would not cost actually more money but that actually might give us more bang for the buck. One would be, which I pushed on, is trying to find as many opportunities for commercial space endeavors which could then bring new revenue into our whole concept. Are there any opportunities there that you see in terms of space exploration and programs you are talking about in terms of attracting new commercial endeavors?

Dr. GILBRECH. Yes, Congressman Rohrabacher, as I said in my statement, we reinstated full funding for the Commercial Orbital Transportation Services. We now have two funded partners with SpaceX, and Orbital Sciences was recently added. We also have five unfunded partners in our Space Act agreements, and we are very encouraged with the progress they are making and we want—we would really like to stimulate this market and get us out of the responsibility of low-Earth orbit cargo delivery. So I see that as budding.

And then we also are encouraged by Google X prize and some of the other things that are really capturing the imagination——

Mr. ROHRABACHER. Thank you very much. I see my time is up. If the Chairman would indulge me one last thought, quickly, one of the other—space commercialization is of course something that could give us more resources. Another area that I have identified is more expanded space cooperation, especially in the Moon effort. I would think anybody who is committed to this project, which I am, would think that the new President of the Untied States or the current President or hopefully a future president, Democrat or Republican, could go and see our friends in Russia and establish a whole new initiative based on a partnership to go to the Moon which the Russians have a lot to contribute which would then open up resources for us to expand our efforts. So I call on the new president to make a new, major initiative with Russia to see if they can become partners in our whole Moon endeavor.

Thank you very much, Mr. Chairman.

Mr. LAMPSON. [Presiding] Many other partners probably would be interested in that, Mr. Rohrabacher. Thank you. And while that line of questioning was going on, Chairman Udall had to respond to another matter and left the chair and has turned over the gavel to me. So I will be sitting in this chair for the next few minutes, and with that, as we move to the second round of questioning, I will recognize myself as acting Chair for the next five minutes.

And let me just throw a question out there for your comments for just a minute, anybody who would like to make a comment on it. Putting aside for a moment the issues that we have discussed today about how best to implement a human exploration program, it appears to me that each of you thinks it is worthwhile for the Nation to undertake human exploration beyond low-Earth orbit. Why do you think it is important for the Nation to explore beyond low-Earth orbit? Who would like to begin?

Dr. GILBRECH. I would certainly lead off since it is my prime job of wanting to get us there. I believe we need to lead space exploration to really be viewed as a global leader and maintain our global preeminence. I also see it as a strategic capability. Whenever you see things that pop up all across in different applications, you should recognize them as strategic capabilities. The Department of Defense uses space, NASA uses space, Marshall is interested in space, our international partners are interested in human exploration of space. So I view that as us to maintain our edge as global leadership. That is probably the key reason.

As was mentioned here, I view also that the Moon is a stepping stone to Mars. Some of the Mars missions, even if I were told that was my prime directorate tomorrow, I would not alter the path I am on today. We have so much to learn from the Moon, and being three days away from home, it would prove out the technologies that we need for a 30-month mission to Mars. I see that as the most responsible and achievable way we can build that kind of an architect. I personally believe there is also a lot of science interest left to be discovered on the Moon. I mean, we had with the Apollo program for all of its accomplishments, we put 12 people on the surface for three-day stints at a time and it is a land mass or surface area the size of Africa; and to say we have exhausted all the scientific discovery there just doesn't compute to me.

Mr. LAMPSON. Anybody else want to make a comment?

Dr. HINNERS. Yes, I would like add to that. You have raised a very basic question, though, essentially, why humans in space? To me it does go beyond the science. Indeed, astronauts can conduct a lot of science activity but also we can do a lot and maybe even a lot more robotically. But humans can add to the accomplishment of science to do things which today and even in the near future are not possible to do robotically or would cost almost as much to do robotically as they do by having the added cost of humans in space.

But I would also add that there is an element of humans that you do not do robotically. Some 30 years ago I was asked that question, and to me it was one of you don't transmit the human spirit through an antenna. You need to be there, in place, in person. So I do support it. And I see that in the young people, the University of Colorado, the engineering students and the science students. They are motivated in space-related things by two things, robotics and human exploration. These kids have something in their psyche that says there is something exceptional about humans leaving the Earth and going out to explore, becoming part of the larger cosmos.

Mr. LAMPSON. Thank you, Dr. Hinners. Dr. Thornton, you testified that human missions to the Moon by the year 2020 are exceedingly unlikely. Why do you feel that?

Dr. THORNTON. Well, I have to say that is not based on any engineering analysis, it is a guess based on Murphy's Law and it is corollary that stuff happens. And stuff that happens rarely accelerates the schedule or reduces the cost. So as I said, it is a guess.

Mr. LAMPSON. Okay. Let me step back from the near-term issues related to CEV and CLV and take a look at the broader exploration program. This Committee and this Congress will be reauthorizing NASA in 2008. What questions and issues do you think are the most important ones for Congress to consider as it examines NASA's plans for exploration beyond low-Earth orbit? Dr. Gilbrech?

Dr. GILBRECH. Well, as been stated here, the question is do we want to get out of low-Earth orbit and go onto our exploration journey, and again, as I said, that requires stability. The answers we are trying to provide is not just an Apollo capability. We are providing an expanded capability that really does build the architecture to go beyond lunar and onto Mars and other destinations. So our architecture will put four people on the surface of the Moon compared to the Apollo program that put three down, three-day stays versus seven-day stays that we will be doing, also, the outpost that we will go into for six-month stays. All of this builds the infrastructure to put the mass in orbit that we will need for the eventual Mars missions. So that would be my answer.

Mr. LAMPSON. Would anyone else comment on that before——

Dr. THORNTON. I would like to know that we have an end-goal in mind, and every step that happens for the next 30 years points toward that goal and not toward dead-ends or false starts.

Mr. LAMPSON. Dr. Hinners?

Dr. HINNERS. Yes. In the 2008 appropriations bill, there is language that prohibits NASA from doing research development or studies on things that are exclusively related to human exploration of Mars. That has a perverse effect of preventing NASA from constructing an integrated exploration architecture. In my mind, one would start with requirements for Mars, feed that back into a lunar architecture, rather than the other way around. And I would like to see the Congress reverse that restriction so that NASA can better construct an integrated, long-term architecture to assure that we are doing the most sensible things in our earlier stepping stones.

Mr. LAMPSON. I will be happy to give you the name of one or two Members of Congress who specifically feel very strongly in this area, and I would love to go with you to go visit them. I might even arrange that meeting if I could get you to come.

Dr. HINNERS. I would be happy to participate.

Mr. LAMPSON. Ms. Chaplain, did you want to make a comment?

Ms. CHAPLAIN. The decision to go beyond low-Earth orbit is a very costly endeavor, so that kind of decision needs to be weighed against all the other discretionary priorities competing for funding and not just within NASA but external to NASA.

It was mentioned earlier that we have issues with terms of prioritizing programs for funding, and that is across the entire government. So when you are looking at something like this that is very long term, it is going to be very costly. You need to make that decision in light of your other priorities.

Mr. LAMPSON. Thank you very much. My time is expired. I recognize the Ranking Member, Mr. Feeney.

Mr. FEENEY. Thank you. The Chair has invited me to participate in that meeting to, and I will be glad to go. On that note, Dr. Gilbrech, Congress as a matter of policy for reasons of compromise which is what we have to do to get things done up here, actually prohibited any money from being spent on the Mars Exploration Program. So at least for this year's budget, we are prohibited from doing what Dr. Hinners has suggested. Has that significantly impacted NASA's development of the Constellation program?

Dr. GILBRECH. Well, as I said, it does have a somewhat chilling effect down at the lower levels because engineers see that and they think, well, you are not even to think of Mars as opposed to the letter of the language that says we will not spend 2008 on anything specific to human landing on Mars. So we are of course following the law. We would hope to see that change in future years. We are trying to develop all of our lunar plans that will be extensible to Mars, and I think that is one of the flexibilities and the beauties of our architecture is that all the things that we are going to do and need to do to survive and prove out these technologies on the Moon will eventually some day pay off for a Mars mission.

Mr. FEENEY. And Dr. Thornton, Mr. Lampson just asked a question about why it is important to have humans in space to do this exploration. A number of scientists have pointed out that it is less risky, it is less costly, and more efficient for some purposes to send robots or to send machines. I note that one of the people that participated in your workshop said that humans should replace unmanned opportunities as soon as possible when exploration has transitioned from reconnaissance to meaning. It went on to say that humans solve puzzles and find meaning in data, albeit at a higher cost than our robotic surrogates. I recently watched one of the new shows suggesting that robots are being developed that can, how do I put this delicately, become romantic partners for humans. I am delighted to hear somebody defend our species, number one, and number two, were there other people who participated in that workshop that gave—in addition to what we have heard from Dr. Gilbrech and Dr. Hinners—reasons why humans need to be part of space exploration?

Dr. THORNTON. We did talk about the goals of science and exploration being different. Whereas humans can help science and science certainly enables the human expansion into the solar system. The basic motivations for that is entirely different. I had a conversation earlier in the week with a professor of anthropology about the migrations of humans around the planet over the last however many thousands of years, and he told me that it is cultures that don't recognize their limits that tend to expand and colonize. Well, I hope that we don't recognize our limits, and I hope that this isn't the generation that decides this is it, we have hit our limits. We are not going anywhere else. So I think it is that inspiration that is part of it. I think it is that drive in us that is part of us. In another workshop, a participant remarked, they don't name high schools after robots. And so it is—you know, I think that is the drive for us to do it. Certainly we need to enable science—the participant who said that humans should replace robots when exploration is transitioned from reconnaissance to meaning was actually one of the scientists, and I was very surprised that the support from the scientists in the group for human exploration as a tool for them. Some of them were very adamant that there are things that humans can do that robots cannot, the intellectual, the putting together of the pieces, the understanding which rock to go after is innate to humans and we don't build robots to do that yet.

Mr. FEENEY. Well, and I have some of the same fears you do that it might be, if we are not careful, 2019 or so before we get back to the Moon, you cited Murphy's Law and others to suggest that that is what you basically get a sense, and that things simply don't get accelerated. But I would point out that at some times on rare instances things do get accelerated around here, and I am afraid that we may need another Sputnik type moment. The Chinese have over 100 universities working on, for example, lunar rover equipment. That is what they admit to. Most of it is done within their defense department which is very shadowy. And Chairman Udall suggested that we don't hope we get back into a space race. The truth of the matter is we just don't know what the Chinese long-term intentions are. They are not part of our international partners. One of the reasons I am going to China is to explore what they are up to and how we can cooperate if possible. But if not, I hope it doesn't take another Sputnik type moment for us to re-energize our human exploration capabilities. And if it does, I sure hope it doesn't come too late to put our program and the workforce and the talents back together. It is a fear I think about every day.

With that, I will yield back.

Mr. LAMPSON. Thank you, Mr. Feeney. I think Sputnik is here. I think the fact that the Japanese have a satellite around our Moon right now, the fact that China has just said that they will beat us to the surface of the Moon. If we don't wake up and respond to that, why should we not believe others will begin to claim our position of technological leadership in this world—if we allow it to happen I believe.

Mr. Rohrabacher. More words of wisdom.

Mr. ROHRABACHER. Thank you very much. I too am concerned about the Chinese, while at the same time I am certainly very positive about cooperation with the Russians. I think the Chinese still maintain the world's worst human rights abusers as a part of their government. I would be very supportive of any efforts that we might have to ensure that the Chinese do not overtake us in space endeavors. And one of the ways we can do that is to make sure that we are being realistic with the limited resources that we have, and I just want to make sure that people who read this record of this hearing that they do not come away thinking there is any type of a consensus that we should be making Mars the driving force for prioritizing our spending. That would be perverse. That would be giving up what we can accomplish today for something that is a majestic dream as we march to the future. But that is not the way to have a realistic and a responsible policy of America's space exploration. Let me just for the record say that I am 100 percent in favor of that limitation saying that we should not be spending money on things that are exclusively for accomplishing a future manned Mars mission. We have other things that we need to do. Do we need to fix the Hubble telescope? The Chairman of this Subcommittee took the leadership on ensuring that we did not just let that asset go, and that cost us some money. Quite frankly, I supported that. Should we be making sure that we have a very robust system for identifying near-Earth objects that may indeed be a threat to the Earth and should we establish a system on how to counteract those threats if we find something headed in our direction? The answer is yes. Should we be utilizing space so we can put a greater effort into conserving and utilizing the Earth's resources for the benefit of humankind? Yes. All of those things cost money. It would be a horrible disservice to the people of the world and especially to the taxpayers of the United States for us to start prioritizing our spending based on the idea of stepping a human foot on Mars 30 or 40 years down the road. That would be a horrible misuse of the money when we have other things that we need to do that can help people right now. So let me make sure that that is thoroughly on the record.

And again, how are we going to make sure that we utilize the resources that we have more effectively? And we have talked about, at least I have brought up today, commercialization and cooperation, and my colleagues have talked about cooperation as well. So let me just say that does not mean that the United States of America should step back from developing its own technology in making sure that we are the leaders in space technology. We can do that by relying perhaps with others to help us produce let us say the less-advanced technologies or give us some insights. Just one last question. I see my time is running out here. Does anyone on this panel have any, and this is just inquiry, does anyone on this panel have any information about any Federal Government agency, including NASA, being involved in any way in anti-gravity research? Just say yes or no, that I do know or don't know. Just right down the line. You don't know? You don't know? Okay. This is just for my own edification. Thank you very much.

Mr. LAMPSON. I have more questions, so if you don't mind, we can continue our questioning.

Dr. Gilbrech, one of the more controversial decisions in the Exploration Program was the decision to develop the Ares I and Ares V launch vehicles rather than modifying the existing evolved, expendable launch vehicle, EELV, family used by DOD. In addition, some have criticized NASA for developing two new launch vehicles rather than a single launch vehicle as proposed in the so-called direct concept. Did NASA examine the alternatives of using either an EELV based architecture or a direct architecture instead of the Ares I and Ares V approach? If so, why did you wind up rejecting those approaches? You can provide a more detailed answer on the record if you want to. Give me whatever you can now.

Dr. GILBRECH. Yes, sir, Congressman. And Mike Griffin elaborated it much more eloquently than I did in his recent speech which was part of the charter of the hearing today. But in summary, yes, those were traded very thoroughly using the evolved expendable launch vehicle as a starting point for our current architecture. It had several weaknesses as far as having to human rate that rocket which has been expendable and not been human rated. It would have also required an upper stage development like the Ares I rocket, so those are some of the challenges there. It also didn't address the heavy lift element that would have required us to go with the Ares V development that we are doing here. So in terms of cost, schedule, and risk, it just did not trade equally with the current architecture that we picked. And that was reviewed and vetted with the Department of Defense, the Government Accountability Office, the Congressional Budget Office, and all agreed that we had picked the best scenario.

The other one you mentioned, the direct launcher, there was a similar architecture like that that was in that exploration systems architecture study. The claims for the direct launcher, we have actually had our Ares projects look at that and we can't justify based on laws of physics the performance that are being claimed by that approach. So we don't claim to have a market on good ideas. We also like to go investigate them and make sure they are credible, and we believe we have the best architecture on the books.

Mr. LAMPSON. Dr. Gilbrech, Dr. Hinners testified that bringing potential partners in early in the concept formation phase where they contribute to structuring the basic approach strikes me as the right way to approach international cooperation. Do you agree? And if no, why not?

Dr. GILBRECH. I agree whole heartedly. In fact, we just had announced our lunar assignments back in October, and we were intentionally leaving the architecture, certain elements of that open to international and commercial participation. We cordoned off certain things we think are critical such as the base transportation infrastructure to get there, the lunar lander, the architecture here, the space suit systems, and the navigation and communication. We want to make sure that those elements get established and that there are certain—for us to lead the specs and the standards of what that does. It is kind of common to—if you fly around the world today, air traffic controllers speak English no matter which airline you are on and there is a reason for that. So there are advantages to taking control of certain aspects of early exploration.

But also are very much engaged. We have a global exploration strategy team that started in 2006. There was over 1,000 participants. Fourteen space agencies have participated. We took over 800 objectives for the lunar environment, both robotic and scientific, and we boiled those down to 180 objectives, and we have also stated six specific goals and that involves all the international communities that are interested in participating with us.

Mr. LAMPSON. NASA was involved in formulating the Global Exploration Strategy Framework for Cooperation. What if any steps has NASA taken since then, is there a concrete plan to implement the strategy, and what are the next steps as you see them?

Dr. GILBRECH. Yes, sir. There is a follow-up working group that will continue to meet and mature ideas. We are working with all the agencies as we go through our cycles of what we think the surface and power systems on the Moon, all the other elements that are up for cooperation as they mature. We want to match each country's desires and their strengths to what we believe they can fill in the lunar architecture so I think we have a very robust communication with the international community and have an open door to them to participate.

Mr. LAMPSON. Dr. Hinners, you indicated in your testimony that ITAR is an impediment to effective cooperation in NASA's Exploration Initiative. Do you have a sense of how much of an impact ITAR could have on our ability to carry out a cooperative lunar exploration program?

Dr. HINNERS. I can't give you a quantitative answer to that, yet I have seen over the years that the ITAR has made it more difficult to first even bring foreign participants onto a site, whether it be a jet propulsion lab or Lockheed-Martin and creates an antagonism that results in an atmosphere of cooperating with you is such a headache, and I am not sure I want to do it. To the degree that we can ease some of the restrictions and make it easier for our foreign partners to actually work directly with us and not feel as if they are outsiders we let in only on a very selective basis, I think we would get better cooperation. I say this all realizing that ITAR has well-intended and necessary functions, so I am not suggesting we try to get rid of ITAR, but to work closely with NASA and the State Department to see if there are ways to make it easier to bring our foreign partners into a closer cooperative environment with us.

Mr. LAMPSON. Anyone else want to comment? Yes, ma'am? Ms. Chaplain?

Ms. CHAPLAIN. I am not an ITAR expert but I know that GAO has issued several reports that show that programs can do a lot to mitigate all the challenges with ITAR if they do planning very much early ahead. And the joint Strike Fighter program was one such program that had to learn how to think through what things they had to work with in ITAR several years in advance. I also believe the Space Station effort has probably given NASA a lot of lessons learned in terms of working under ITAR, so they should go back now and see, like, what kind of foundation do we need to lay now so that we don't have some of these issues later on.

Mr. LAMPSON. Thank you very much. Mr. Feeney, you are recognized.

Mr. FEENEY. Yeah, just on the ITAR point, one of the things that the Administrator asked us for this year is relief from the ITAR situation with respect to the Soyuz which unfortunately will be serving the International Space Station for a short period. I know that some folks that like me want to narrow or eliminate the gap have suggested that we simply not re-enact ITAR to force Congress' hands to fund an elimination of the gap. I think that is a very high-risk strategy and would be worried about people who are suggesting that must be buying lottery tickets to take care of their retirement years because that is a big gamble.

By the way, I think Congressman Rohrabacher is no longer here. I think he said it right, when there is no consensus about whether we ought to go to Mars, I think he must clearly think that that is a great ultimate destination that will help inform, I think as Dr. Hinners has suggested, the way we take the interim steps. But in addition to Mars, are there other destinations, near-Earth objects for example? Every dozen or couple dozen billion years we have an asteroid, you know, that literally strikes—or meteorite that strikes and not just does damage but dramatically changes the planet and we have a lot more potential impacts on a smaller scale. Are there destinations that would be useful in the ultimate goals of the vision as set out? And Dr. Hinners or Dr. Thornton, do you want to address that?

Dr. THORNTON. There are some——

Mr. FEENEY. Somewhere in between Moon and Mars.

Dr. THORNTON. There are some intermediate goals that we could look at both for technology development and for science. One is near-Earth asteroids. Those missions could be a year or so, and that could be our first step out of the Earth's gravity well and longer duration flights. Also, missions to the moons of Mars which would be similar duration to Mars missions but would not require landing and launch systems to get people there and back. And so there are some destinations that would advance both the technology and the science between now and a mission to Mars.

Mr. FEENEY. Dr. Hinners, anything to add?

Dr. HINNERS. I would agree with what Dr. Thornton has said, and missions to Sun-Earth Lagrangian points as they are called and then near-Earth objects can incrementally what I call stress the systems. Today you would not dare undertake a three-year transit to and from Mars, and developing that capability is not going to be easy. But I think doing it incrementally and not going for three years first but maybe one month to the Lagrangian points and then many months, maybe half-a-year, to a near-Earth object could cause us to get on a path of incremental development. Also that would feed back into using LEO which still has some uses to develop some of these capabilities. The International Space Station in which we have invested somewhere between $35 and $40 billion just in development exclusive of launch costs, if you put a major investment there, let us milk that investment, not excessively obviously, but let us make the best use of that investment to help develop these future capabilities.

Mr. FEENEY. Well, on that note, Dr. Gilbrech, we are getting down into some of the details of the programs that we are working on. The COTS Program was originally conceived to include opportunities for both cargo to the station and crew. We have not funded any of the crew potential. Is that a priority for NASA? If it is something that you had some additional funding, would you prioritize? What is the potential for crew development capabilities before 2015 when we have the Constellation up and working?

Dr. GILBRECH. Yes, well, you are correct. Right now. Our funded agreements only go through the uncrewed, the cargo capabilities. So we are currently doing analysis on what it would take to accelerate that crew capability with our current COTS partners of the commercial market right now, and we are in the final stages of vetting that and we would be happy to share some of the details of that with this committee. We view any and all sources to close the gap as ones we should be pursuing vigorously.

Mr. FEENEY. And Ms. Chaplain, that is one private program that is not under NASA direct management and control. What should Congress be watching for as COTS is developed specifically?

Ms. CHAPLAIN. You are correct that this is under a different kind of funding mechanism, and traditionally government agencies don't get that same kind of insight that they have when it is a more traditional contracting mechanism. But as I understand it in this case, NASA does have some insight into these key gates that the COTS program will be passing through, things like critical design review and the flight readiness testing. So again, as with the Ares and the Orion, at these key gates, you want to take some criteria and see how well the programs bounce up against it, including technology readiness, design readiness, production readiness. There is a pretty important test coming up on SpaceX. Their return to flight mission for their Falcon 1 vehicle, and that will tell us a lot, if they have good standing going forward for participating with the Space Station, if this test coming up is successful.

Mr. FEENEY. And just briefly, Dr. Gilbrech, do you have some high level of confidence that COTS is on target right now based on NASA's involvement?

Dr. GILBRECH. Yes, sir. This first element of COTS that we funded in exploration is the Space Act Agreement, and that is where NASA is basically a co-investor in development technology. And we track them and their milestones, and that includes the reviews that Ms. Chaplain identified. We also work with them on visiting vehicle requirements. It ensures they know how to approach and dock with the International Space Station safely. So, they are making good progress. This is a tough business. SpaceX, we recently renegotiated some of their milestones. They are all technical problems that we would normally expect in any type of a new rocket development program. So that resulted in a six-month slip from their original planned demo of cargo in September 2009 to March 2010, but again, this is nothing out of the ordinary that alarms us so we have high confidence.

Mr. FEENEY. Mr. Chairman, my time has expired. If I could ask one more question, I think I am done for the day. Thank you for your indulgence and your leadership here.

I mentioned that I am going to China. I have some real concerns because I don't believe we know the long-term intentions of the Chinese. I think that they will be fairly friendly until after the Summer Olympics this year. After that, you know, a lot of us just don't know what their intentions are; but their capabilities with respect to developing deeper water naval capabilities, a dramatic increase in defense funding, and especially in space are very impressive and I think we have to pay close attention. Having said that, one area that I sort of lean towards immediate cooperation with the Chinese is to share the potential capability for the Chinese Shenzhou vehicle to hook up with the Space Station without necessarily agreeing to do it or not. It would be an alternative to relying on the Russians or the potential development of COTS crew capabilities. Does anybody have some last-minute advice before I head off to Beijing on that specific issue?

Dr. GILBRECH. Well, I think from my perspective, you know, China is participating in the Global Exploration Strategy but we have no current collaboration with them, and I would have to defer to my counterpart in Space Operations and our Administrator for those discussions.

Mr. FEENEY. Okay. Dr. Hinners?

Dr. HINNERS. I would add I would encourage you on your trip, I was a participant in the '70s in working with the Soviets and made six not-so-fun trips to Russia, at that time the Soviet Union.

Mr. FEENEY. Vodka is good, isn't it?

Dr. HINNERS. But in that environment which was not a friendly environment at top levels during the Cold War, we did make good progress. We were able to I think use the Space Program as a political arm if you will and accomplish things jointly that contributed to furthering the eventual Soviet Union, now Russia, that is more democratic.

So I look on the Space Program as an opportunity to help work some of the world's political problems.

Mr. FEENEY. Thank you. And thank you, Mr. Chairman.

Mr. LAMPSON. Thank you, Mr. Feeney, good questions. Dr. Gilbrech, it has been reported that NASA's planned Ares V heavy-lift vehicle is not able to meet its lunar mission requirements as currently conceived and will need some beefing up. Consequently, the agency is said to be studying a variety of options to boost the lift capability of the big, new rocket. If this is so—is this so, first of all, and if so, what options are under consideration?

Dr. GILBRECH. Yes, sir. This is a very challenging mission, and as I said before, we are putting much more capability on the lunar surface to be able to go potentially to a six-month outpost. That requires a lot of lift capability to trans-lunar injection. And right now our current target for Ares V is 65 metric tons of lift, and we see that with the capabilities that we are maturing for our lunar architecture that we would like to push that beyond that. And we have concepts now to take it up to 75 metric tons and involve upgrades of the solid-rocket motor with the propellant grains. There are concepts of going from five R68 engines to six R68 engines. We are looking at other weight-saving measures as far as composite casings for the five-segment booster, potentially making them—not recovering them, making them expendable and saving some weight in the parachute system. So we have got a suite of options that we are considering, and again, we will just have to mature those. But it is a challenge.

Mr. LAMPSON. What is it likely to do to the five-year funding requirements?

Dr. GILBRECH. Well, the Ares V funding really doesn't kick in until 2011, so right now our current budgets—these are all just trades that we are looking at, concept trades, as the deign matures. So right now I don't see any impact in our current budget horizon, but we certainly would inform the Congress if we saw that that was going to be an issue that we needed to raise up.

Mr. LAMPSON. Thanks. Dr. Hinners, what do we need to accomplish on the Moon to enable human exploration of Mars or other potential destinations as called for in the President's *Vision for Space Exploration* and what enabling techniques required for human exploration to Mars cannot be accomplished on the Moon?

Dr. HINNERS. From what I have seen of the lunar architecture, one of the prime things it will contribute is how to even exist and operate for a long time on a planetary surface, and lunar habitat at an outpost would help accomplish those goals. What it will not do is develop the capability for the long duration space flight that is necessary for a Mars mission. We talked about that previously. There are other elements of Mars. The environment at Mars is so different from that at the Moon that a lot of things you do on the surface of the Moon have relatively little applicability to eventual Mars human exploration. For example, the in-situ resource utilization, on Mars you would use probably, at first go-around, the atmosphere—of course, on the Moon there is no atmosphere—for developing a technique to use lunar regolith might not have much capability but it would advance some of the engineering, where the whole concept of in-situ resource utilization is [inaudible] potential engineering problems that we have and started to face.

So in many ways I think the lunar exploration is a stepping stone but not the most important ones that we will eventually need if we are going to Mars with humans.

Mr. LAMPSON. Dr. Thornton, would you comment?

Dr. THORNTON. I would agree with that. I agree with Dr. Hinners about the engineering challenges of building a semi-permanent outpost on the Moon, can lead us to solving some of those problems on Mars. The physiological issues of getting from Earth to Mars in long duration space flight are something we probably will not solve on the Moon, but some of the other intermediate steps of going to the Earth-Sun Lagrange points or going to near-Earth asteroids can lead us a step further down the road to solving those sorts of problems.

Mr. LAMPSON. Dr. Hinners, let me ask some questions regarding NASA exploration's architecture. What do you see as the greatest risk that needs to be addressed in preparing for human exploration beyond the low-Earth orbit?

Dr. HINNERS. The greatest risk in my view is inadequate budgets that will cause us to either so reduce the requirements that we are not making much real progress in developing a capability or stretching it out so far that we are investing the bulk of our funding in just staying in place and not making good progress in getting beyond where we are today.

Mr. LAMPSON. I was going to ask you about something that would lead slightly differently. I thought maybe you would give a little different answer than that, but how do we address that? I was going to ask you to address the perspectives on NASA on how NASA would address that risk, but how should Congress address the risk that you just presented to us of funding?

Dr. HINNERS. I wish I had a good answer for you. The old proverbial one of more money obviously is not an acceptable answer today with the budget situation that we have. The only alternative is for NASA to very carefully look at its step-wise approach to be sure that we are doing just those things that will lead to the development of the essential ingredients of the lunar architecture. Let me give you an example, and some of my science friends would not be very enamored with this. But the outpost, if you are looking at stepping stones, has much more utility than science-driven sortie missions, even though science sortie missions may give you more immediate return. So if one has to make a choice, I would say do the outpost and not the sortie missions. You may have to make choices like that.

Mr. LAMPSON. Do you believe that NASA's exploration architecture is robust and capable of accommodating risks?

Dr. HINNERS. I can't answer that. I don't know enough about the details. You could answer on that?

Mr. LAMPSON. Dr. Gilbrech or anybody else, would you care to comment on any of those questions?

Dr. GILBRECH. Yes, I would be glad to. I believe the architecture is robust, it is flexible, it can handle the pay-as-you-go environment that we find ourselves in. We also, as far as being stuck in a lunar outpost mode, we have talked about that with the lunar architecture teams as far as what is logical exit strategies, when do we consider we have learned enough to say that we don't need a permanently manned outpost at the lunar surface. Some of the things that we have learned on the International Space Station, which has humans permanently in space for the last seven and one-half years is we learn a lot more with that extended presence than we do on 14-day Shuttle missions. So really, the outpost has a lot of value in the fact it will drive out a lot of problems we wouldn't necessarily find on seven-day sortie missions. They complement each other, but I think they are both necessary.

We also are learning a lot on the International Space Station about the six-month transit time that it takes to go to Mars. There is a lot of things we are learning about microgravity, bone loss, muscle atrophy, radiation exposure, some of the things that we worry about for the astronauts on that long journey. The Moon is a good analog for Mars as far as the gravity effects and whether one-sixth gravity on the Moon, you have one-third Earth gravity on Mars. Howe does that counteract some of these bone loss and other effects that we see in microgravity.

So we hope that we can answer some of those long-range questions with the lunar analog. And as far as in-situ resource utilization, we also want to follow the water, and if we can find water on the Moon which is why we are choosing some of our landing sites at the south pole, we can learn how to make fuel, oxygen that we could potentially apply to a Martian site if we were to find water on Mars.

Mr. LAMPSON. Thank you very, very much. I would be remiss if I would allow the comments that Mr. Rohrabacher made about not wanting to make a priority about going to Mars. I think that he maybe slightly misunderstood some of the point that was made here. Obviously, we want to learn things, regardless of what we are doing through our efforts. I would hate to see us turn a blind eye to Mars and not include that in the mix as we go through all of this. But my point, and then I will call on you, Dr. Thornton, was what we learned when there were those who said we shouldn't even be trying to go to the Moon. But it affected me personally when I had my Lasik surgery. The tracking that the machines the ophthalmologist used was an adaptation from what we have used and do use in docking and even weapons and many other kinds of things that we have used in space. The advancements that have been made on heart surgery I had a year ago are significant. Those things are affecting millions of lives on this planet. The return that we get from our exploration, from our willingness to explore where we haven't been I think is absolutely critical.

What would you like to say or add?

Dr. THORNTON. In the 1980's, the tag line for the International Space Station, and as an astronaut I was part of the PR machine, started out, the next logical step, and then it morphed to a permanent outpost in space, when we lost sight of what that was a step to. And in the process, NASA engaged a lot of scientists in areas of microgravity science and life science and nurtured those fields and grew them and funded them because they would be the users of the permanent outpost in space. Again, I was part of that and my last mission was a Space Lab mission, and a lot of those experiments were on there only because it was a warm-up for their permanent stay on a space station. In 2004, we changed our mind and we turned off a lot of those people, we unfunded a lot of those people, we basically ended their career in that field. We ended those fields. In retrospect, not having a view of what this was a step to was not responsible as far as how we treated people, nor how we handle the taxpayers' money. And that is what I would like to not see on the Moon. I think there are a lot of things we can learn on the Moon on our way to Mars but to not have a vision of what it is a step to I think is what is irresponsible.

Mr. LAMPSON. Thank you very, very much, and you are going to be making the last word. Well, no, you are not. Mr. Feeney?

Mr. FEENEY. I don't have anymore questions, but I just wanted to on the international cooperation front share with the Committee and the people in the audience that at 10:45 today the ATV hooked up with the International Space Station. The European Space Agency now is a prominent national space enterprise. I think we have—do we have some people in the audience from the European Space Agency? If you don't mind raising your hand, well, congratulations. We were very thrilled with the news, and with that I want to thank the witnesses and the Chairman again.

Mr. LAMPSON. Thank you, Mr. Feeney, and I thank each and every one of you for being here. I think it has been an interesting conversation, and I look forward to more of them, to future meetings.

If there is no objection, the record will remain open for additional statements from Members and for answers to any follow-up questions that the Subcommittee may ask of the witnesses. Without objection, so ordered. This hearing is now adjourned.

[Whereupon, at 11:56 a.m., the Subcommittee was adjourned.]

Appendix:

ANSWERS TO POST-HEARING QUESTIONS

ANSWERS TO POST-HEARING QUESTIONS

Responses by Richard J. Gilbrech, Associate Administrator, Exploration Systems Mission Directorate, National Aeronautics and Space Administration (NASA)

Questions submitted by Chairman Mark Udall

Q1. Cost growth and systems that do not work are often attributed to inadequate oversight and abrogated testing. NASA systems have had their share of cost growth, lengthened schedules, and terminations in the past. Is it technically and programmatically feasible to accelerate Orion's Initial Operating Capability (IOC) to earlier than March 2015 and still conform to the thorough review and testing process required by NASA's own agency-wide program management guidance? If not, what requirements is NASA considering relaxing?

A1. Yes, it is technically and programmatically feasible to accelerate IOC. NASA has planned and paced the multi-decade Constellation program to live within its means, while carefully identifying and mitigating the threats to mission success. Within the Constellation program, NASA is making important decisions to stay within budget and on schedule by striving for the lowest life cycle costs possible. NASA has established an initial plan for Constellation's designs and integrated flight tests to ensure that the Agency adequately tests systems prior to their operational use and allows appropriate time to implement critical lessons learned from these tests.

Full funding of NASA's FY 2009 budget request for Constellation is needed so that NASA can continue successful transition between the Shuttle and the Orion and Ares I. The FY 2009 budget request maintains Orion IOC in March 2015, at a 65 percent cost confidence level, and full operational capability (FOC) in FY 2016, though NASA is working to bring this new vehicle online sooner.

NASA has a dedicated group of civil servants and contractors who work together to check and cross-check the multiple variables that go into designing and eventually operating these future Exploration vehicles. As such, NASA has sufficient insight into the progress and status of the program/project with inserted key decision points that determine the readiness of the program/project to progress to the next phase of the life cycle. These phases are defined such that they provide a natural point for a "Go/No-go" decisions to proceed based on pre-defined exit criteria for that phase.

Currently, all activities are on schedule. The Ares I and Orion projects recently completed their Systems Definition Review (SDR) and the Preliminary Non-Advocate Reviews, which confirmed that NASA is employing a strong systems engineering approach to refine the current program requirements and properly allocate those requirements at the project level. The Constellation Program does not anticipate relaxing any requirements. Orion and Ares I Projects are currently proceeding toward their individual project level Preliminary Design Reviews (PDR) by the end of this year.

These reviews provide opportunities to confirm that the subject activities, products, and process control requirements have been adequately distributed to—and implemented within—the projects. The projects, along with the programs, are tracking all products required for PDR to insure all data is available on time and at the appropriate maturity level.

Q2. We understand that NASA engineers are adding instrumentation to the first full scale Ares I–X flight vehicle to gather data about the severity of possible vibrations from the solid-fuel first stage. What is the range of possible mitigation approaches under consideration and what are the commensurate estimated cost and performance impacts of each? Will the funds needed to address this issue come from Constellation's reserves? How serious would the issue need to be before the March 2015 IOC date was determined to be in jeopardy?

A2. Thrust oscillation is a common risk in solid rocket motors because thrust oscillation or resonant burning is a characteristic of all solid rocket motors, like the First Stage of the Ares I launch vehicle. In November 2007, NASA chartered the Thrust Oscillation Focus Team (TOFT) to review the forcing functions, models and analysis results to verify the current predicted dynamic responses of the integrated stack, identify and assess options to reduce predicted responses, validate and quantify the risk to the Ares I vehicle, Orion spacecraft, crew, and other sensitive subsystems and components, to the extent allowed by the Ares I/Orion design maturity, and establish and prioritize mitigation strategies and establish mitigation plans consistent with the Constellation Systems Program (CxP) integrated schedule.

Mitigation strategies being reviewed include reducing or eliminating the forcing function; canceling or isolating the forcing function; de-tuning the stack from the forcing function; and reducing loads conservatism that initially made the scale seem more serious. NASA is evaluating tuned mass absorbers to reduce loads. We are collecting motor performance data on the upcoming Ares I–X and Shuttle flights as well as launch acceleration data at the crew seats. NASA chartered a small team to evaluate and propose potential concepts to de-tune system frequencies. Finally, we are evaluating internal motor design modifications that could potentially reduce thrust oscillation.

The TOFT results will be factored back into the Ares and Orion projects this summer and cost estimates will be developed as the projects progress to PDR this year. As stated before, thrust oscillation is not uncommon during the development of solid rocket motors, and NASA is confident in its ability to mitigate this risk. Therefore, thrust oscillation should have no impact on the March 2015 IOC.

Q3. What, if any, role is NASA considering for Ares V to support future science missions? Would a role for science missions be considered as ancillary or central to the development of Ares V?

A3. The Ares V launch vehicle is in the formulation stage of design and development. The NASA Science Mission Directorate (SMD) is taking initial steps to understand the potential value of this heavy launch system to the space and Earth science missions of the future.

In November 2007, SMD requested that the National Research Council (NRC) initiate a study on the science applicability of the Ares I, Ares V, and Orion Constellation system elements based on a comparison of projected capabilities of these systems with available long range mission concepts for space and Earth science.

The NRC recently released the interim report from this study, an initial survey based on already-available analyses of a portfolio of 11 "Vision Mission" concepts provided by NASA. The NRC found that, of the 11 candidates, seven appeared likely enough to benefit from the Ares V capability (as compared to an EELV implementation) to warrant further study for implementation on a heavy lift vehicle. However, the NRC also found that the greatly-increased payload mass enabled by an Ares V launch could result in significant total mission costs.

In parallel with development of the initial report, the NRC issued a Request for Information (RFI) to explicitly evaluate the increased payload mass capability of Ares V on science mission concepts. In addition, NASA's recent workshop, held at the Ames Research Center, focused on astronomy mission opportunities presented specifically by the Ares V. The findings of this workshop, which considered seven missions (three in common with the Vision Missions set) and a number of relevant technology topics, is being provided to the NRC for its second phase study. There are plans for a second Ames workshop in early August to broaden the range of planetary science mission candidates available for analysis. The final report of the NRC study should be available in November 2008.

Ultimately, each of the concepts evaluated through these workshops and studies, and any other Ares V candidates, will be appraised by the appropriate upcoming NRC decadal survey to find its place in SMD's priority queue for implementation.

Note that the primary requirements for Ares V will be dictated by the U.S. Space Exploration Policy's goal of exploration of the solar system; science will be a secondary use of the capability. NASA is working proactively to understand potential scientific use and identify opportunities to optimize science applicability of exploration systems via design changes that do not interfere with their primary function.

Q4. Dr. Hinners testified that "one should have a lunar program exit strategy. . .." Does NASA have an exit strategy from the Moon, and if not are there any plans to create one?

A4. The *NASA Authorization Act of 2005* (P.L. 109–155) specifically calls on NASA to establish a sustained human presence on the Moon for a number of inherently valuable reasons in itself and also as a stepping stone to the exploration of Mars and other destinations. While no specific "exit strategy" exists, NASA is proceeding in a manner that builds towards future exploration of other destinations and with an "open" architecture that seeks to build up international and commercial involvement in the lunar outpost, in part, to help NASA ensure it has the ability with time to venture beyond the Moon.

The challenges of missions to future destinations beyond the Moon are the same as those for any significant exploration endeavor beyond low-Earth orbit: long-duration space flight and non-Earth gravity effects on human physiology and psychology; orbital assembly of a spacecraft with the transportation technologies and crew support systems for a successful journey; living, operating, and surviving on planetary environments with inhospitable environments; and many others. These challenges are technically complex and interrelated. NASA is designing its lunar efforts, as much as possible, to reap the unique benefits of returning to the Moon in its own right, as well as building forward, decreasing risk and as test-bed for future exploration beyond the Moon.

NASA is proceeding in a manner which both maximizes learning opportunities and leverages international and commercial participation. NASA is implementing a strategic approach to this direction, creating a coordinated global approach toward exploration beyond low-Earth orbit, and will establish an infrastructure that can efficiently support all human exploration missions regardless of destination. Over the long-term, this infrastructure should remove the burden from the U.S. tax payer for paying all costs of development and operations in human space flight, making any eventual mission to Mars and other destinations more affordable.

It is NASA's belief that establishing a sustainable presence on the Moon provides the broadest possible suite of opportunities relevant to learning about Mars and other exploration destinations (e.g., living and operating on another planet, learning about complex assembly of space systems and gravitational transitions on the human body). More importantly, however, it provides the best opportunity for creating that global infrastructure, as these technology developments provide opportunities for new services and industries dedicated to the support of human space exploration. Additionally, creating a sustainable lunar presence provides diverse opportunities for fostering partnerships and collaborations with international space agencies and preparing the larger community for space exploration.

Q5. The National Research Council just released its report "Managing Space Radiation Risk in the New Era of Space Exploration." *The report was requested by NASA. NRC was tasked to establish a committee to evaluate the radiation shielding requirements for lunar missions and to recommend a strategic plan for developing the radiation mitigation capabilities needed to enable the planned lunar mission architecture. Do you agree with the findings and recommendations in the report? What are you doing to implement its recommendations?*

A5. NASA agrees with the major recommendations of the NRC Report, and is implementing a program that is as well-balanced as possible within available resources to implement the recommendations and their respective priorities.

- The Report noted that the biological uncertainty in assessing the health risks from space radiation exposure is the most important problem for managing space radiation risk to human explorers. This assessment agrees with previous recommendations from the NRC and the IOM, and the current funding distribution in space radiation in the Human Research Program reflects primary importance in understanding and quantifying human health risks, especially cancer.
- The ability to accurately predict solar particle events is essential in preventing astronaut exposure to acute radiation exposure. In this area, NASA has relied on its own space research (currently in Science Mission Directorate) along with a history of successful collaboration with other federal agencies, especially National Oceanic and Atmospheric Administration (NOAA) and National Science Foundation (NSF). Intra-agency and inter-agency discussions are ongoing to continue this collaboration and assure that appropriate solar monitoring systems are in place during exploration missions to the Moon and beyond.
- This NRC Report made numerous recommendations on shielding technology, engineering and design. NASA agrees with these recommendations and is working internally to assure that as much materials research as prudent and possible is conducted to enable mission and system designers to implement radiation protection at all phases of planning and implementation.
- Finally, the NRC pointed out that there are important health risks other than cancer that may result from exposure to space radiation, e.g., cataract, nervous system, and cardiovascular risks. NASA agrees that this is an important problem, and is implementing research in this area within its current resources.

Q6. The NRC report also lists a number of technology investments to enable lunar missions with astronauts. These include radiation biology research, research on solar particle events, and experimental data for shielding design. How will NASA translate these recommended investments into funding requirements? Where will such funding likely be placed?

A6. The Human Research and Exploration Technology Development Programs within the Exploration Systems Mission Directorate (ESMD) support a variety of radiation biology and shielding research projects. The Human Research Program is conducting ground and space-based research to reduce the large uncertainties in radiation exposure risk. Experiments to evaluate the effectiveness of shielding materials and to validate radiation transport models are being performed at the Brookhaven National Laboratory. In FY 2011, NASA is planning to begin a new project to develop radiation protection technologies in the Exploration Technology Development Program. This project is scheduled to start sufficiently early to ensure that radiation shielding will be ready in time to support construction of the lunar outpost. Funding requirements will be determined during project formulation by assessing the remaining uncertainties in radiation exposure risk and the effectiveness of state-of-the-art shielding materials, and then developing a plan to advance shielding technology to meet performance targets. NASA is flying the Cosmic Ray Telescope for the Effects of Radiation (CRaTER) instrument on the Lunar Reconnaissance Orbiter (LRO) mission to help agency planners understand the radiation environment around the Moon. LRO is planned to launch by the end of the year.

Research on solar particle events is conducted within NASA in the Science Mission Directorate (SMD). ESMD is currently coordinating its solar particle research needs and "space weather" predicting needs with SMD and other agencies through the NASA Office of Chief Engineer, which has developed a "cross-cutting" technology implementation process to ensure that NASA's immediate research and operational needs are optimized in this important area, including coordination with other agencies. NASA considers current investment levels and priorities timely to enable human lunar exploration in the post-2020 time frame.

Q7. You testified that NASA is looking into various options for increasing the capability of Ares V and that "we will just have to mature those." *What is your timeline for further analysis of these options and when would you expect to have the information needed to make a decision?*

A7. NASA is currently reviewing lunar operations and surface concepts to provide parameters for the Constellation program transportation requirements. This will ensure we have the transportation system understood well enough to proceed with Ares V requirements development. As a component of this review, NASA is developing options to meet potential transportation needs. The review will be completed this summer, at which time NASA will mature the appropriate options. Results will be factored into the Ares V development efforts as it progresses through its formulation activities.

Q8a. You testified that "technically integration across all elements, the Orion, the first stage, the upper stage . . . making sure that everything is properly integrated is one of the biggest challenges in my mind." *How do you plan to deal with this risk?*

A8a. NASA understood from the beginning that integrating all the diverse systems (Orion, Ares, Ground Systems, Mission Control, etc.) would be one of the biggest challenges of the Constellation Program. Integration challenges are natural occurrences within any endeavor that is not an "off-the-shelf" commodity procurement. Acquisition of a complex system first requires clear program authorities. With this in mind, NASA established a clear program and project structure by which to manage the end-to-end system level requirements and empowered the Constellation Program Office to oversee the system integration of the Program elements. The second step is to have a clear process by which to communicate needs and difficulties up the chain of authority so Agency and Program resources (i.e., experts, tools, funding, etc.) can be brought to bear quickly on the inevitable problems that will occur. Third, resource reserves must be readily available within the Program's execution year budget so the issues that arise can be effectively dealt with by the Program and Project managers. If funding reserves are not sufficient in the execution year, then existing "fixed" resources have to be re-prioritized which will result in work deferral and schedule slippage.

Q8b. Are you confident that the current NASA Constellation workforce has the depth of systems integration experience to handle the integration risks you describe?

A8b. NASA is very confident in the caliber and ability of our Constellation team, which includes both government and industry, to accomplish this complex system acquisition. The Agency is not dependent on the development of exotic new technologies to make this program a reality. Our challenge is the integration of complex systems that must work together. Issues will inevitably arise. The question is how we respond when they do arise and whether we have the necessary resources at hand to solve the issues. Efforts to date show great promise, as evidenced by our work solving the issues related to thrust oscillation.

Q8c. What other inputs would help to mitigate this risk?

A8c. Another key input to mitigate this risk is for the Congress to enact stable funding consistent with NASA's budget requests in order to have adequate resources at hand to implement program activities and resolve challenges that arise.

Questions submitted by Representative Nick Lampson

Q1. Dr. Hinners testified that "one should have a lunar program exit strategy. . .." Does NASA have an exit strategy from the Moon, and if not are there any plans to create one?

A1. The *NASA Authorization Act of 2005* (P.L. 109–155) specifically calls on NASA to establish a sustained human presence on the Moon for a number of inherently valuable reasons in itself and also as a stepping stone to the exploration of Mars and other destinations. While no specific "exit strategy" exists, NASA is proceeding in a manner that builds towards future exploration of other destinations and with an "open" architecture that seeks to build up international and commercial involvement in the lunar outpost, in part, to help NASA ensure it has the ability with time to venture beyond the Moon.

The challenges of missions to future destinations beyond the Moon are the same as those for any significant exploration endeavor beyond low-Earth orbit: long-duration space flight and non-Earth gravity effects on human physiology and psychology; orbital assembly of a spacecraft with the transportation technologies and crew support systems for a successful journey; living, operating, and surviving on planetary environments with inhospitable environments; and many others. These challenges are technically complex and interrelated. NASA is designing its lunar efforts, as much as possible, to reap the unique benefits of returning to the Moon in its own right, as well as building forward, decreasing risk and as test-bed for future exploration beyond the Moon.

NASA is proceeding in a manner that both maximizes learning opportunities and leverages international and commercial participation. NASA is implementing a strategic approach to this direction, creating a coordinated global approach toward exploration beyond low-Earth orbit, and will establish an infrastructure that can efficiently support all human exploration missions regardless of destination. Over the long-term, this infrastructure should remove the burden from the U.S. tax payer for paying all costs of development and operations in human space flight, making any eventual mission to Mars and other destinations more affordable.

It is NASA's belief that establishing a sustainable presence on the Moon provides the broadest possible suite of opportunities relevant to learning about Mars and other exploration destinations (e.g., living and operating on another planet, learning about complex assembly of space systems and gravitational transitions on the human body). More importantly, however, it provides the best opportunity for creating that global infrastructure, as these technology developments provide opportunities for new services and industries dedicated to the support of human space exploration. Additionally, creating a sustainable lunar presence provides diverse opportunities for fostering partnerships and collaborations with international space agencies and preparing the larger community for space exploration.

Q2. In responding to my question on what you would do with a significant funding increase, you identified more robust flight test programs as one of the areas you would target. Please expand on your response, including what risks NASA is taking with less flight testing and how you are mitigation such risks.

A2. NASA's current flight test program for its Constellation Program is robust and meets mission needs. The flight test program is designed to provide risk mitigation opportunities by providing in-flight assessments of the design and operational characteristics of the hardware from early development through the first crewed flights. The flight test program begins with two non-orbital developmental flights that will provide early engineering data for the Ares and Orion Project Critical Design Reviews. The first of these two development flights is the first pad abort test at the White Sands Missile Range in New Mexico, planned for December 2008. This will be followed up with the Ares I–X flight from the Kennedy Space Center planned for spring 2009. The Ares I–X flight will use a simulated upper stage with a simulated Orion Crew Exploration Vehicle and will provide flight data to verify our predictions from wind tunnel testing on vehicle flight dynamics and controllability.

The second phase of the Constellation test program (after the two developmental flights) includes the continuation of the Orion launch abort system test campaign, and the continuation of the vehicle flight tests. The Orion launch abort system test campaign is designed to gather information at key operational envelope boundaries and under simulated failure conditions and the flight tests will provide engineering evaluation of the new design and gather additional critical flight data to validate engineering models used for design certification. Current plans call for testing the high altitude abort case in combination with flight testing of the first five-segment first stage on the Ares I–Y mission. Ares I–Y will test the first stage motor's thrust oscillation behavior and the dampening features being designed. It will also test the separation of the first and upper stages before triggering a high altitude abort.

Ares I–Y is followed by the Orion 1 flight, planned to be the first dress rehearsal for the end-to-end flight of the entire integrated Ares and Orion vehicle using all actual flight hardware. Orion 1 is scheduled to take place before flying a crew on the Orion 2 flight at Initial Operating Capability, scheduled for March 2015. The multiple and significant test objectives for Orion 1 are aimed at evaluating all aspects of the design and operation of the flight and ground systems that can be accomplished without an on-board crew. (Later tests, however, will involve a crew onboard.) In addition, the engineers will utilize the non-crewed Orion 1 orbital flight to evaluate the Orion systems on-orbit. During that flight, the mission controllers will be able to gain experience operating the entire actual flight hardware system and validate the training simulations.

As stated earlier, NASA believes its current flight test program is adequate to meet mission needs. However, additional testing within any program or project can yield benefits.

Additional test flights could provide opportunities in three areas:

First, an additional unmanned orbital flight would allow objectives to be shared across two flights, and would provide a built-in opportunity to retest given the reasonable expectation that we will experience in-flight technical anomalies. Further, given the early formulation phase of the development, Orion 1 flight planning is not yet mature enough to know which test objectives can't be accomplished on a single flight and must be deferred to subsequent crewed flights.

Second, additional test flights would provide additional experience and data on the inherent reliability of the launch system, including data on the critical staging event and test of the upper stage and modified J–2X engine.

Finally, an additional orbital flight test would allow a second re-entry test using alternate or backup controls on a dispersed or emergency trajectory to assess stability and heat shield performance.

Q3. NASA's ability to secure a $3.3 billion increase to the Constellation budget in FY 2011 is predicated on the full availability of funds freed up from retiring the Shuttle. However, transition costs after retiring the Shuttle will not be known until the FY 2010 budget, at the earliest. Will the March 2015 IOC date slip if projected Shuttle retirement transition costs exceed NASA's cost goal of less than $500 million? If not, what will be the impact on the rest of NASA's programs?

A3. NASA is preparing an integrated Shuttle Transition and Retirement (T&R) cost estimate as part of the FY 2010 budget formulation process that will become the basis for a T&R budget line in the FY 2010 President's budget request for NASA. Currently, both the phasing and estimate are in work, thus it would be speculative to assess impacts given the complex interactions. The Constellation program is currently carrying Shuttle T&R costs as a threat against their budget starting in FY 2011 and NASA is working a number of options to reduce the estimated cost. Preliminary indications are favorable, and NASA currently does not envision an impact to the March 2015 initial operational capability of Orion/Ares from T&R costs.

Q4. Dr. Hinners testified on NRC report recommendations for successfully conducting scientific activities within an exploration program and on collaborations between the Exploration Systems Mission Directorate and the Science Mission Directorate regarding science in the exploration initiative.

Q4a. How do you see science fitting into exploration and how would you describe that fit?

A4a. The fundamental goal of the U.S. Space Exploration Policy is to advance U.S. scientific, security, and economic interests through a robust space exploration program. While U.S. scientific interests are not the sole driver for returning to the

Moon, these interests have been represented in the architecture development process from the beginning.

NASA has numerous mechanisms to ensure scientific analysis and input are integral components of its lunar exploration planning. Both of NASA's Lunar Architecture Teams (LAT–1 and –2) included active Science Focus Elements with representation from Science Mission Directorate (SMD) at NASA Headquarters, Constellation, and scientists across the Agency. As the definition of the lunar architecture has matured, the LAT Science Focus Element Team has engaged scientific and other external communities in workshops, studies, and community events, including NASA Advisory Council's (NAC) Workshop on Science Associated with the Lunar Exploration Architecture (Tempe Workshop) and the Workshop on Architecture Issues Associated with Sampling (in conjunction with the LEAG and the OSEWG, described below). The Science Focus Element participated in all LAT meetings to consider the impact of design options and payload manifesting on scientific productivity.

Q4b. What further plans does NASA have regarding the integration of science and exploration?

A4b. As NASA continues the planning and development of the Lunar Architecture, NASA has established the Outpost Science and Exploration Working Group (OSEWG) at NASA Headquarters to continue the productive working relationships between the Science, Exploration, and Space Operations Mission Directorates and between Headquarters-level and working-level exploration planning and requirements definition. The OSEWG will ensure the continued engagement of science, including scientific input into requirements definition, as NASA strives to implement the U.S. Space Exploration Policy. In addition to any work or studies that the OSEWG might perform, it may also commission studies by groups such as the Lunar Exploration Analysis Group (LEAG), the Curation and Analysis Planning Team for Extraterrestrial Materials (CAPTEM), and the Field Exploration Analysis Team (FEAT). Since LEAG and CAPTEM are under the umbrella of the NASA Advisory Council, this provides a solid mechanism for ensuring that the necessary expertise is being drawn upon at appropriate junctures in the exploration planning process to ensure a balanced and inclusive approach to the exploration architecture.

The Science and Exploration Systems Mission Directorates are working together at all levels, from research to space flight missions, and from daily interactions to senior management meetings. Examples of ESMD and SMD jointly supporting research included the competitively selected grants through the Lunar Advanced Science and Exploration Research (LASER) program.

SMD and ESMD are working closely on the space flight missions under ESMD's Lunar Precursor Robotic Program (LPRP). SMD has provided a Program Scientist and Program Executive for the Lunar Reconnaissance Orbiter (LRO) mission. After its first year of operations, when LRO has achieved its primary exploration objectives, SMD will take over LRO operations to pursue lunar science objectives. ESMD and SMD are cooperating in the planning for the International Lunar Network (ILN). ESMD is providing the Radiation Assessment Detector (RAD) and Mars Entry Descent and Landing Instrumentation (MEDLI) on SMD's Mars Science Lander (MSL) mission.

The OSEWG co-chairs from ESMD and SMD meet weekly to work science and exploration integration, with the full OSEWG meeting biweekly. Current subgroups of the OSWEG are focused on the incorporation of science inputs based on the NAC and NRC recommendations into the ESMD's requirements documents, the development of science scenarios on the lunar surface for use by the Constellation Architecture Team, and the integration of science and exploration activities here on Earth that are analogs of future lunar surface activities. ESMD and SMD senior leadership meet regularly through mechanisms such as the Partnership Integration Council and ESMD–SMD Roundtables. Integrating science and exploration has been and remains a high priority at all levels within both SMD and ESMD.

Questions submitted by Representative Tom Feeney

Q1. It is likely that NASA will be forced to operate under a FY 2009 Continuing Resolution which would reduce the Constellation funding to the FY 2008 level. Please describe how this situation will likely affect Constellation's development schedules. Assuming the 65 percent confidence levels, would this jeopardize the March 2015 launch date? If so, how much would this lengthen the gap?

A1. Full funding of NASA's FY 2009 budget request for Constellation is needed to continue successful transition between the Shuttle and the Orion and Ares I. The

FY 2009 budget request maintains Orion IOC in March 2015, at a 65 percent confidence level, and full operational capability in FY 2016, though NASA is striving to bring this new vehicle online sooner. A full-year Continuing Resolution (CR) at the FY 2008 level would result in a loss of approximately $350M to NASA's Exploration Systems Mission Directorate. A number of factors would affect the impact of a full-year CR, and NASA is still assessing those variables.

Q2. Will the new capabilities of the Constellation system enable new or unique science opportunities that have heretofore been impossible?

A2. Yes, the Constellation program plans to develop the Ares V Launch vehicle, required to enable human lunar return. Ares V could provide more than 130 metric tons (MT) of cargo to Low Earth Orbit (LEO). By comparison, the current fleet of Evolved Expendable Launch Vehicles can provide only approximately 25 MT to LEO. The greater launch mass capacity permits larger, heavier and more complex scientific payloads, and greatly reduced cruise times for planetary missions. The much greater diameter and volume of the Ares V fairing could decrease the need for complex deployments of large structures and thereby reduce payload cost and risk.

NASA's Science Mission Directorate (SMD) is taking initial steps to understand the potential value of this heavy launch system to the space and Earth science missions of the future. In November 2007, SMD requested that the National Research Council (NRC) initiate a study on the science applicability of the Ares I, Ares V, and Orion Constellation system elements based on a comparison of projected capabilities of these systems with available long range mission concepts for space and Earth science. The final report of the NRC study should be available in November 2008.

Q3. Recently Jet Propulsion Laboratory (JPL) did an assessment of the Ares V launcher for planetary and other science missions. As a result of this or other studies, please discuss the proposed utility of the Constellation architecture for use by planetary and other science missions?

A3. Ares V is at an early stage of definition and development. Nonetheless, Science Mission Directorate is taking initial steps to understand the potential value of this heavy launch system to the space and Earth science missions of the future. The JPL study, *"Ares V: Application to Solar System Scientific Exploration,"* submitted in January 2008, describes a number of enabling advantages of the Ares V over EELV systems.

According to the JPL study, there appears to be a wide range of Science missions that could be launched by Ares V that would not be possible otherwise. Ares V capability is expected to open up lunar, Mars, near-Earth and solar system missions for heavy payloads, and might even enable reasonable sample return missions from the far reaches of the Solar System. Furthermore, Ares V, configured with an upper stage, could enable NASA's ability to search for life at the far reaches of our solar system.

Q4. The Space Shuttle budget does not contain any funds for program close-out activities after 2010. This represents an as-yet-to-be-determined threat to the Constellation program, recently estimated at about $1.2 billion. It appears there are insufficient reserves in the Constellation program to handle this, so how do you expect this shortfall will affect the Constellation program?

A4. NASA is preparing an integrated Shuttle Transition and Retirement (T&R) cost estimate as part of the FY 2010 budget formulation process, which will become the basis for a T&R budget line in the FY 2010 President's budget request for NASA. Last year's $1.2B estimate for T&R costs from FY 2011–2015 developed, during the FY 2009 budget formulation process, is considered conservative and much higher than the expected estimate from this year's FY 2010 budget formulation process. Reasons for this include Constellation program requirements maturation, more clearly defined property disposition guidelines, better understanding of facilities requirements, and improved communication and effective coordination among all relevant process stakeholders. This year's FY 2010 budget planning T&R estimate is not yet known, as both the phasing and estimate are in work. Thus it would be speculative to conjecture on possible program impacts. The Constellation program is currently carrying Shuttle T&R costs as a threat against their budget starting in FY 2011, and NASA is working a number of options to reduce the estimated cost. Preliminary indications are favorable, and NASA currently does not envision an impact to the March 2015 initial operational capability of Orion/Ares from T&R costs.

Q5. In previous years NASA intended to carryover unobligated funding from one year to the next to help smooth the funding profile during development and initial production of the Constellation system. However, Congressional appropriations bills did not endorse this principal. How has NASA been able to compensate for the lack of carryover funding to keep Constellation on schedule?

A5. While Congress has discouraged the use of the two-year obligation authority that is legally available to most Constellation program funding, the Program has been able to use obligated-but-uncosted funding to smooth the funding profile and maintain schedule. Obligated-but-uncosted funding carried forward from FY 2008 and FY 2009 will be used to maintain the development schedule in FY 2009 and FY 2010.

Q6. NASA decided against using the Space Shuttle Main Engines in the design of the new Ares launch vehicle and instead chose to modify the J–2. The J–2X engine development is acknowledged to be one of the greatest risks to the timely development of the Ares launch system. What is the status of this engine development?

A6. The J–2X is an evolved version of two historic predecessors: the powerful J–2 engine that propelled the Apollo-era Saturn I–B and Saturn V rockets, and the J–2S, a simplified version of the J–2 that was developed and tested in the early 1970s. By utilizing the J–2X, NASA eliminates the need to develop, modify, and certify an expendable Space Shuttle engine for the Ares I. NASA expects the J–2X to be less expensive and easier to manufacture than the Space Shuttle main engine. Although the J–2X is based on the J–2 and J–2S engines used on the Saturn V, it also leverages knowledge from the X–33 and RS–68. NASA also is planning significant upgrades to the engine, which essentially makes the J–2X a new engine development program. Therefore, NASA has taken steps to mitigate J–2X risks by increasing the amount of component-level testing; procuring additional development hardware; and working to make a third test stand available to the contractor earlier than originally planned.

The J–2X is progressing through its critical design phase and is, in fact, the first Constellation program element to reach this phase of the development effort. Subsystem Critical Design Reviews (CDRs) are progressing through the summer with the J2–X CDR being scheduled for later this year. Technically, engine development and testing has begun. Initial Powerpack 1–A test phase concluded in May 2008. Initial engine cold flow nozzle side load testing has been completed. NASA has begun testing the J–2X gas generator at the MSFC. Additional subsystem tests will be conducted throughout the remainder of this year and into next year. On August 23, 2007, NASA broke ground on a new rocket engine test stand at Stennis Space Center in Mississippi. The test stand will provide altitude testing for the J–2X engine and will allow engineers to simulate flight conditions at different altitudes. Testing on the A–3 stand is scheduled to begin in late 2010.

Q7. The Exploration System Architecture Study *(ESAS, Chapter 6, p. 385) concluded that "The considerable additional cost, complexity, and development risk were judged to be unfavorable, eliminating RS–68-powered Cargo Launch Vehicles." Hence, the RS–68 powered launch vehicles, as represented by LV–29 (Chapter 6 p. 421), were not selected for further evaluation in the lunar architecture trades. However, shortly after the ESAS was released, NASA decided to replace the Space Shuttle Main Engines with the RS–68 engines on the Ares V. Following this decision to switch to the RS–68 for the Ares V, did NASA go back and reevaluate the other RS–68 powered variants contained in Appendix 6a of the ESAS study? If not, why not?*

A7. Post-ESAS, NASA looked at several RS–68 powered Cargo Launch Vehicle (CaLV)—now known as the Ares V—variants and nearly all of them fell well short of the two launch Crew Launch vehicle (CLV)/CaLV performance requirement. After extensive trade studies, the key feature that was discovered that allows the current Ares V approach to reach the performance required for a two launch solution is expanding the core stage diameter to 33 ft. (Saturn V diameter). This option had not been reviewed during ESAS.

Q8. On April 10, 2008, NASA provided a background paper comparing the planned Ares launch vehicles with the DIRECT launcher proposal. The paper makes a number of assertions that are not corroborated with data. Please provide the detailed analysis, including the Integrated Master Schedule, launch system performance, technical assumptions, and cost estimates, used to compare the Ares I and Ares V launch vehicles with the Jupiter-120 and Jupiter-232 Shuttle derived variants.

A8. Our assessment of the DIRECT–Jupiter 232 was calibrated to Ares and Constellation ground rules and assumptions, using NASA tools and design standards. We found that the delivered gross lunar lander mass for DIRECT falls ~50 percent below the reported value for an Earth Orbit Rendezvous-Lunar Orbit Rendezvous (EOR–LOR) mission (20.8 mt vs reported 40.9 mt). This assumes no on-orbit cryogenic tanking, which DIRECT requires. On-orbit cryogenic refueling is a highly complex and operationally risky proposition for this mission class. Even with on-orbit tanking, DIRECT falls short by more than 25 percent (based on adjusted EOR–LOR payload capability and idealized available on-orbit propellant). For a LOR–LOR mission, proposed in May by DIRECT, our assessment found that the delivered lander mass fell ~80 percent below the reported value (8.4 mt vs reported 50 mt). This approach cannot meet NASA performance requirements.

Additionally, the DIRECT proposal contains many claims and has no substantiated or detailed cost, schedule or reliability data on which to make any assessments—hence no comparison can be made. However, based on previous experience and study, several conclusions can be drawn:

DIRECT claims that improvements in cost and schedule would be achieved by leveraging existing Shuttle Reusable Solid Rocket Motors (RSRMs) and RS–68 engines and implies that only modest modifications to the STS external tank (ET) would be necessary. No data is presented to back up the proposed development cost savings for the DIRECT approach.

The Jupiter's STS ET-based core stage would require a major development effort, which, in turn, would drive cost up and a longer schedule when compared with the current Ares approach. DIRECT claims requirements to strengthen ET sidewall and inter-stage structures on the Jupiter common core are achieved by milling less material during manufacture. NASA has extensively examined such approaches over the past 20 years and concluded that this effort incurs significant expense and development with marginally applicable STS ET heritage: the Jupiter common core requires a new main propulsion system, new thrust structure, new avionics, new forward LOX tank structure and a new payload shroud, substantial intertank/Lox Hydrogen tank redesign and aft Y-ring interfacing and a completely new stack integration effort. In addition, recurring ET manufacturing is costly and labor intensive compared with the lower cost, all friction-stir-welded approach being used on the Ares vehicles. The Jupiter core stage engine, the RS–68, would be required to be human rated. Though feasible, it would require a significant development effort and an extensive engine test program. In addition, DIRECT is taking on development of a new, Saturn V S–II class Earth Departure Stage (EDS) for lunar capable missions. DIRECT proposes to develop low boil-off rate technology and integrate it into the EDS tanks. NASA has studied this type of approach extensively in the past. This type of development effort will incur significant near-term technology expenditures before full-scale development can proceed.

Per flight costs for Orion missions also favor the Ares approach. The Ares I vehicle will have less cost per flight compared with the Jupiter 120 heavy lift counterpart: one five-segment RSRM versus two four-segment boosters and an upper stage with one J–2X versus a core stage with two or three RS–68s.

Such development efforts would require new, dedicated acquisitions at the same scale as the current Ares I procurements, which have taken ~2 years to put in place.

The DIRECT report claims Jupiter launch vehicles provide increased safety and performance margin as a primary advantage over Ares launch vehicles. DIRECT includes very little data, calculations, or analysis to support these safety assertions. Such a probabilistic risk assessment requires substantial effort by system and subsystems experts to conduct. In reality, safety/reliability for crewed missions favors the current approach. The Ares I vehicle has a reduced number of propulsion systems required for ascent, which will increase its safety/reliability over a Jupiter approach: one five-segment RSRM versus two four-segment boosters and an upper stage with one J–2X versus a core stage with two or three RS–68s plus an EDS powered by a J–2X for lunar missions.

Finally, on July 3, 2008, the Agency provided to Subcommittee staff, via web link, the NASA Performance Assessment of DIRECT 2.0 reflecting additional background information and analysis related to the DIRECT proposal.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Cristina T. Chaplain, Director, Acquisition and Sourcing Management, Government Accountability Office

On April 3, I testified on GAO's work related to the Ares I and Orion programs, which comprise NASA's future cargo and crew transportation system. Our work has generally found that there are considerable unknowns as to whether NASA's plans for thee vehicles can be executed within schedule goals as well as what these efforts will ultimately cost. This is primarily because NASA is still in the process of defining many of the project's performance requirements and some of these uncertainties could affect the mass, loads, and weight requirements of the vehicles. The following responds to your follow-up questions for the record.

Questions submitted by Chairman Mark Udall

Q1. You indicate that the Orion and Ares I will soon undergo preliminary design reviews (PDR).

a. Why are these reviews so important? What answers should NASA receive at that time?

b. If answers are not received, what are the consequences of NASA proceeding without them?

A1. The Ares and Orion preliminary design reviews occur shortly before NASA will be formally making a long-term investment commitment to the programs. Therefore, these reviews are critical to demonstrating that NASA has the knowledge it needs to proceed, i.e., that it fully understands its requirements and the resources (dollars, technology, time, expertise, facilities, etc.) needed to meet these requirements. For example, NASA should understand technologies and hardware involved with the Ares and Orion systems as well as their design enough to know how long it will take to complete work and what that work will cost. Our work on major system development efforts across the government consistently shows that when programs make long-term commitments without this knowledge, they invariable experience technical and other problems that require more time and money than anticipated to resolve and often result in reduced capability.

Q2. NASA indicates that its current level of reserves in Constellation is less than eight percent.

a. In your review of space systems acquisitions, what is the percentage level of reserves usually prescribed and built into program budgets at the stage the Constellation program is at?

b. Are they usually used up?

A2. In my experience, when reserves are set aside for space programs, they are used up quickly. This is because estimates regarding cost, time, complexity, etc. were highly optimistic to begin with. Before we can recommend a standard reserve level that should be used, agencies need to commit to starting programs only when they have demonstrated appropriate levels of knowledge about what they are trying to achieve and what resources are needed to do so. Once this discipline is in place, agencies can use reserves as a technique for mitigating risks, and can realistically expect their initial level of reserves to be sufficient.

Q3. You indicated concern about uncertainty and NASA being able to execute both the Orion and Ares I programs within schedule and cost targets.

a. What is the reason behind this uncertainty?

b. Are there any other approaches to developing Orion and Ares I that would minimize uncertainty?

c. How would this approach impact the projected gap in American access to space?

A3. As our testimony notes, uncertainty about costs and schedule stems from significant gaps in knowledge which exist about both the Ares and Orion programs. For example, NASA does not know if the Orion vehicle will be landing on land or water at this point. Without this knowledge, it cannot estimate the cost of the vehicle, since each option presents different cost and technical challenges. In addition, NASA is still working through uncertainties about the engine it is producing for the launch vehicle, vibration issues, engineering challenges related to the upper stage of the launch vehicle, and a host of other technical and production challenges.

Again, until has a better understanding of what's involved with addressing these risks, it will not fully know what dollars and time are needed to complete the projects. NASA recognizes that it needs to close these knowledge gaps before completing its preliminary design reviews.

Q4. Ms. Chaplain, in the past, NASA's projects have experienced significant cost growth and schedule delays. Such a pattern, however, cannot be repeated as competition for resources will likely continue to increase as the amount of discretionary spending decreases. Congress has asked GAO to conduct periodic assessments of selected NASA programs in order to identify cost, schedule, and risk factors on each program. I understand from my staff that you will be modeling your work on major NASA systems after an annual assessment the GAO does on DOD weapon systems. Please explain what this assessment is and how it will help to achieve our goals for bringing more accountability and transparency to NASA's spending.

Q4a. What are some of the challenges GAO faces (e.g., access to information, securing accurate life cycle cost data, etc.) in carrying out this work?

A4a. Overall, GAO has had good support from NASA's office of Program Analysis and Evaluation (PA&E) for completing the review. Undertaking a job of this magnitude and introducing a new methodology to NASA has been and was anticipated to be quite a challenge. Several issues have added to this challenge, including the following:

- GAO has had to spend a large amount of time educating PA&E and NASA's projects on the methodology. We have held numerous meetings with HQ PA&E officials since November trying to explain to them our methodology and why we are asking for some of the data. In addition, large amount of follow up have been required due to the need to educate the projects on the methodology. This process has been very time consuming.
- PA&E has requested that all data be filtered through their office. While this process is good for trying to ensure consistency and a shared understanding of what is required, it has led to additional time delays and GAO not receiving all information requested. In addition, this has led to the unfortunate consequence of projects directing their questions to PA&E instead of GAO. This added layer of communication has led to miscommunication and delays.
- GAO continues to await the receipt of cost and schedule information for projects in formulation. GAO is still in the process of negotiating with PA&E on what will be provided in terms of cost data for projects in formulation. The likely outcome is that GAO will be provided the independent estimate of life cycle cost for each of the projects in formulation. This process has been time consuming.
- Consistent information is not available on all NASA projects given the various requirements that have been modified over the years for NASA's projects (i.e., NPR 7120.5 iterations) and cost accounting has changed practically every year.

Q4b. What types of information should NASA be collecting from its projects to monitor their performance? To what extent is this information being collected?

A4b. NASA should be collection information on and monitoring their projects with the types of indicators that we have found in our best practices work, including technology maturity and design stability. In addition, NASA should ensure that it questions its projects on their estimates for reuse of heritage technology; margins for weights growth; strategies for contractor management; strategies for dealing with project partners (i.e., other government agencies or other countries); and software development plans, in particular the estimated numbers of lines of code.

Q4c. Based on early observations, does NASA seem to be experiencing similar problems on each of its development efforts?

A4c. Preliminary indications show that many NASA project are experiencing cost and schedule growth due to several common issues. Some of these include:

- Proceeding beyond preliminary design without maturing technologies.
- Proceeding beyond critical design with an unstable design.
- Underestimating development activities (i.e., cost and schedule) associated with the use of heritage technology.
- Dealing with contractor performance issues.
- Dealing with partner performance issues.

Questions submitted by Representative Tom Feeney

Q1. Given that COTS is being privately developed under a Space Act Agreement without the contractual controls of a typical NASA procurement, what specific criteria should Congress focus on to gain insight while COTS is being developed?

A1. Key milestones that should be tracked under the COTS efforts include preliminary design reviews, critical design reviews, and production reviews. At each of these reviews, the COTS provider should be able to demonstrate it has knowledge necessary to proceed forward. For example, at critical design review, best practice organizations have typically released 90 percent of their design drawings, which ensures that the design is stable enough to proceed into complex integration activities. It is our understanding that NASA participates in these reviews to assess readiness to move forward, and payments to the COTS providers are based on successfully completing these reviews. Test flights—the results of which are often visible to the public—are also important to monitor as they demonstrate whether engines work properly and ultimately, whether prototype launch vehicles can successfully reach orbit. There are also key indicators that should be tracked throughout the development programs, including weight growth and software growth—as these are typically underestimated in complex space programs. However, we do not know the extent to which this data is available to the Congress and oversight entities.

Q2. What specific criteria and critical decision milestones should Congress focus on to gain insight while Ares I is being developed?

A2. The same milestones and data points should be tracked in assessing the Ares program, in addition to the results of specific types of testing, such as software testing and integration testing. Further, Congress should continually monitor NASA's own risk assessment process as it helps to identify what the agency deems as the most critical risks and challenges facing the project as well as its mitigation plans. In addition, earned value management (EVM) analyses should be tracked as they can pinpoint where contractors are having trouble and what trends are being experienced in terms of cost and schedule growth. Lastly, the levels of management reserves should be tracked as the pace of deploying those reserves can indicate areas of high risk.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Noel W. Hinners, Independent Consultant

Questions submitted by Chairman Mark Udall

Q1. You testified that "one should have a lunar program exit strategy. . .." What, in your view, would such a strategy look like and are there any lessons learned from the Apollo program?

A1. An exit strategy should define the desired goals of the program with sufficient clarity and precision that one knows when the program may be considered successful and thus ended. This requires that the program requirements that flow from the goals be defined and "flowed down" to the program element designs and mission implementation plans. For the lunar program, the goals and related requirements should be defined in terms of what information is needed, for example, to provide the experience and capability development essential (not simply possible) for preparing for exploration beyond the Moon. Those goals and related requirements should be guided by an integrated exploration architecture that flows requirements backward from what is required for eventual Martian exploration and develops capability in the most efficient and effective venue (Earth, ISS, Moon and other deep space missions, e.g., Lagrange or Near Earth Objects).

If there is a relevant lesson learned from Apollo it is that there was essentially no exit strategy. The end of Apollo was dictated by external political and budgetary forces that, for example, resulted in the cancellation of Apollo 18, 19 and 20. NASA plans for extended lunar exploration totally failed to materialize. I believe that the greatest problem was not recognizing, or accepting, that the budget situation simply would not support the plans for extensive lunar exploration. At the time NASA had other planning underway for an Apollo Applications Program, for a Shuttle and a Space Station but did not have administration or Congressional approval for any, a vacuum that led to inefficient structuring of the subsequent human flight program. Explicit approval and acceptance of a post-lunar program (i.e., an integrated architecture more specific than the top-level Vision for Space Exploration) would help avoid a similar situation today.

Q2. You testified that various auxiliary equipment and facilities required for a lunar outpost are enabling for future exploration of Mars and could be provided by international partners, given the funding challenges for Ares I and Orion. Are you indicating that our potential to go beyond the Moon will depend on the auxiliary equipment that international partners choose to contribute to the lunar exploration initiative?

A2. No. The equipment referred to is lunar specific. Our potential to go beyond the Moon to, say, Lagrange points or Near Earth Objects will not require most of the auxiliary equipments developed for the Moon. The lunar equipment also will not be directly applicable to eventual human exploration of Mars because of the great environmental differences although some of the techniques and experience could be applicable. I do believe, however, that the experience that can be gained by developing a truly collaborative lunar exploration can help develop the trust that will be needed for collaboration in a program as difficult as Martian exploration. Given the high cost of human exploration of Mars it is likely that significant international collaboration will be an essential requirement.

Q3. A committee convened by the NRC found that the lack of knowledge about the biological effects of and responses to space radiation is the single most important factor limiting prediction of radiation risk associated with human space exploration. If this is the case, are we proceeding in the design of space hardware without a good understanding of the radiation protection requirements needed?

A3. I am not sufficiently knowledgeable in this subject to be able to provide an answer.

Questions submitted by Representative Tom Feeney

Q1. How should Congress ensure that the establishment of a lunar outpost does not divert attention and resources away from exploration beyond the Moon?

A1. There are several ways to help avoid unwarranted investment in the Moon. First, NASA must have a well-defined integrated exploration architecture that defines a next step(s) beyond the Moon and which clearly spells out what capabilities unambiguously require lunar development (as contrasted with on Earth, ISS, Lagrange and/or NEO missions). Having a post-lunar or possibly concurrent goal such as, e.g., a Lagrange mission, helps prevent a tendency to continue with or expand whatever one is doing simply to keep going with something. Secondly, have a well-defined lunar exit strategy (see answer to Chairman Udall's question #1 which is keyed directly to accomplishing specific, well-defined and not open-ended goals. Lastly, the lunar program should be limited to only the high priority goals; one must resist the temptation to make it a program for all comers as happened in the formulation days of both the Shuttle and the ISS.

Q2. What are the most important objectives to be accomplished in returning humans to the Moon? And to what extent are those objectives prerequisites for exploration beyond the Moon?

A2. It is my belief that the most important lunar objectives are those related to preparing for exploration beyond the Moon. I do not at this time see the lunar program as having merit as a long-duration (decades) permanent "occupancy" or mostly for conducting science.

Q3. How is NASA ensuring that lunar explorations will be focused on achieving high potential scientific returns?

A3. The NASA Science Mission Directorate is using the NRC report *The Scientific Context for the Exploration of the Moon* to provide it with guidance on what lunar science to pursue. They are working directly and jointly with the Exploration Systems Mission Directorate to plan the science activities for the Moon. As noted in my testimony, I believe that the quality of the potential science can be improved by following the management model used by Apollo to integrate the science into the lunar human exploration.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Kathryn C. Thornton, Professor and Associate Dean, School of Engineering and Applied Sciences, University of Virginia

Questions submitted by Chairman Mark Udall

Q1. Earlier this year you helped organize a workshop entitled "Examining the Vision: Balancing Science and Exploration" *held at Stanford University. I understand that participants were scientists and engineers representing various industry, academic, government, and nongovernmental organizations. What, if anything, did participants propose be done to counter concerns that the effort to develop a lunar infrastructure would bog down space exploration beyond the Moon?*

A1. The only output from the workshop was a joint communiqué[1] listing four consensus statements. Opinions express in this document are my own.

Workshop participants concluded that "the purpose of sustained human exploration is to go to Mars and beyond," but specific strategies to keep that goal in the forefront of NASA, Congress and the public were not discussed at the workshop.

Since the Vision was announced in 2004, NASA has necessarily directed abrupt changes to ongoing programs in order to accommodate new mandates with the expectation of only incremental funding increases. Termination of the Space Shuttle program is in work. Science programs on ISS that do not support the Vision have been effectively terminated. Reduction and possibly elimination of support for ISS operations in the next decade is, in my opinion, inevitable as NASA presses forward with construction of a lunar-based analog to the ISS.

If the Moon is a stepping stone to Mars and beyond, as I believe it is, exit strategies should be built into the plans from the beginning. Start dates, stop dates and objectives to be accomplished in between should be part of the lunar strategy. Rather than prohibiting NASA from planning for a human exploration program on Mars, Congress should *require it* so that our investment in a lunar program is an investment in a comprehensive exploration program.

Q2. You testified on the consensus statements of the workshop on Examining the Vision, *one of which states that "The significance of the Moon and other intermediate destinations is to serve as stepping stones on the path to that goal." What, in your view, is needed from the lunar stepping stone to move on to other destinations, and are NASA's plans on the right path for meeting those needs?*

A2. Until goals for human exploration of Mars and beyond are developed, it is not possible to determine precisely how intermediate steps can contribute to those goals. However, in very broad terms, human missions to the Moon would provide the first opportunity in a generation to manage and execute a program of this magnitude. Heavy lift launch capabilities and new human transport to LEO would presumably be building blocks for missions to other destinations. The Ares I and Ares V launchers should, like the Atlas and Delta families, evolve over the years to accommodate progressively more demanding requirements for missions beyond the Moon.

Q3. At the Stanford workshop, the inadequacy of NASA's budget to do all the things it is expected to do was also raised.

Q3a. Did participants address whether Vision is still achievable if NASA's future budgets remain at current historical levels?

A3a. While there was no consensus on the subject, the feeling among several of the workshop participants is that additional funding, on the order of a few billions per year, would be required to achieve near-term goals of the Vision, i.e., Orion, Ares I and Ares V, while continuing to fund space science, Earth science and aeronautics.

Q3b. Were lesser priority activities identified for elimination/reduction so that Vision activities could continue?

A3b. Elimination and prioritization of NASA activities were not addressed at the workshop. A two-day workshop could not take on specific budget issues, with the exception of noting budget cuts being applied to science and aeronautics programs to compensate for under-funded exploration mandates, including the Space Shuttle retirement.

[1] *http://www.planetary.org/programs/projects/advocacy_and_education/space_advocacy/20080214.html*

Q4. Your testimony comments on whether we should look at a broad range of opportunities for scientific research on the Moon or focus on the science that will best enable capabilities for exploration beyond the Moon.

Q4a. What is your perspective on which path NASA should take?

A4a. In an ideal world, we would do both. In the less-than-ideal world in which we live, it seems unlikely NASA can afford both options. In that case, focusing on the science and technology developments that will best enable exploration beyond the Moon opens up a much broader array of science opportunities in the solar system that can be enabled or enhanced by human activities than just those on the lunar surface.

Q4b. What, if any, concerns do you have regarding scientific exploration of the Moon?

A4b. The Moon is a profoundly interesting destination for human and robotic scientific exploration with a wealth of compelling objectives, enough to keep us busy for a generation or two. My concern is that expectations for a lunar outpost must be realistic, have a finite lifetimes and be part of an overall plan for exploration.

NASA long range budget forecasts have been presented as "sand charts" to show that the exploration strategy through 2020 is affordable assuming inflationary budget growth or slightly higher.[2] Had "sand charts" been available in the early 1980's showing ISS funding being phased out only seven years after completion, the space station we have now might be considerably different. My point is not to rehash the 25+ year saga that led to the ISS, but to suggest that we not repeat that experience. Similar "sand charts" extending to 2040 or 2050 could serve as visual reminders that resources are finite, and lunar program budgets must at some time ramp down to make way for the next step in the exploration strategy.

Questions submitted by Representative Tom Feeney

Q1. If we stay-the-course with our current plans, do you think the exploration architecture as currently envisioned is sufficient to allow us to accomplish our goals of establishing a permanent human outpost on the Moon and attempt voyages beyond? Please elaborate.

A1. I cannot comment with any authority on the merits of the current architecture as compared to other alternatives, except to note that second guessing, re-architecting and redirecting are probably not productive exercises at this point. A more productive effort, in my opinion, would be to direct and fund NASA to begin considering requirements for voyages beyond the Moon and how the Constellation system can evolve for those purposes.

Q2. There is general agreement that the Moon is a logical stepping stone to further destinations including Mars. Would you comment briefly on other potential destinations that are not as far away as Mars that could serve as useful interim destinations?

A2. Developing a comprehensive exploration strategy and associated technology development roadmaps should be done by experts. I can only comment in very general terms.

Missions to Near Earth Objects of perhaps a year's duration would further extend human exploration beyond Earth's gravity well. Technology required for the health and safety of human crews in the interplanetary environment would be directly applicable to missions to Mars.

Human missions to the Martian moons would be of a similar distance and duration as expeditions to the Martian surface, but would not require expensive and risky landing and launch systems.

These intermediate goals and others offer rich science opportunities as well as steps along a technology roadmap to Mars.

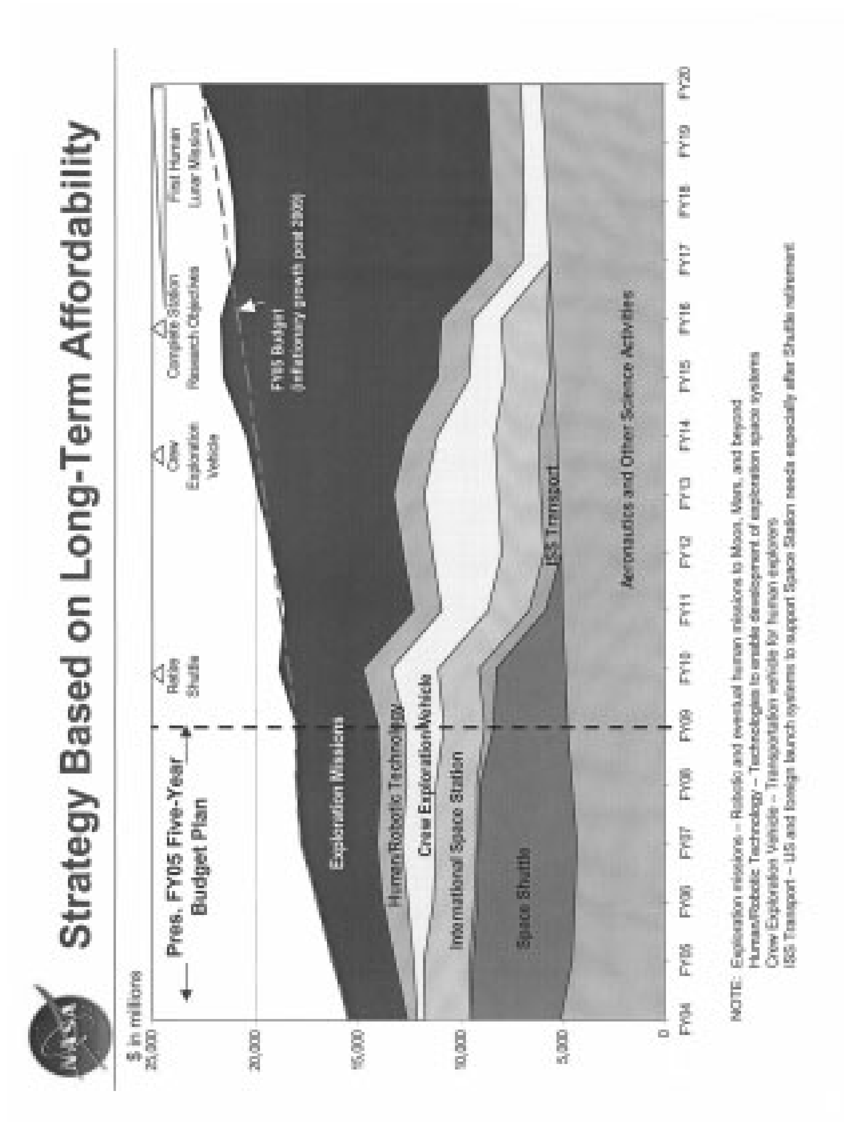
Q3. How should Congress ensure that the establishment of a lunar outpost does not divert attention and resources away from exploration beyond the Moon?

A3. In my opinion, Congress should direct NASA to develop a comprehensive exploration strategy and technology roadmap to accomplish the goal of the Vision to "extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations." "Go as you pay" may necessitate smaller steps that I would like to

[2] *http://history.nasa.gov/sepbudgetchart.pdf* (attached)

see, but makes it even more important to ensure that each step contributes to the overall goal.

Attachment


Strategy Based on Long-Term Affordability
$ in millions
25,000
20,000
15,000
10,000
5,000
0
Pres. FY05 Five-Year Budget Plan
Retire Shuttle
Crew Exploration Vehicle
Complete Station Research Objectives
First Human Lunar Mission
FY05 Budget (inflationary growth post 2009)
Exploration Missions
Human/Robotic Technology
Crew Exploration Vehicle
International Space Station
Space Shuttle
ISS Transport
Aeronautics and Other Science Activities
FY04
FY05
FY06
FY07
FY08
FY09
FY10
FY11
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FY14
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FY20
NOTE: Exploration missions – Robotic and eventual human missions to Moon, Mars, and beyond
Human/Robotic Technology – Technologies to enable development of exploration space systems
Crew Exploration Vehicle – Transportation vehicle for human explorers
ISS Transport – US and foreign launch systems to support Space Station needs especially after Shuttle retirement