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

HEARING CHARTER

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 FY 08 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%?*

    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 FY2011 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 spaceflight program was clearly articulated in the 2005 NASA Authorization Act. Specifically, the Act directed the NASA Administrator *"to establish a program to develop a sustained human presence on the Moon, including a robust precursor program, to promote exploration, science, commerce, and United States preeminence in space, and as a stepping-stone to future exploration of Mars and other destinations.*

The Administrator was further authorized to develop and conduct appropriate international collaborations in pursuit of these goals."

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 FY 09 budget provides $3.50 billion for the Exploration Systems Mission Directorate (ESMD). From a direct cost perspective[1], the proposed FY 09 budget for ESMD is an increase of $357.4 million from that appropriated in FY 08. 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 FY 09 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 FY 09 is $173 million—an increase of $42.5 from that enacted in FY 08. ESMD plans to complete its demonstration of Commercial Orbital Transportation Services (COTS) in FY 10. The commercial procurement 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 FY 09 is $452.3 million, a decrease of $218.8 million from the $671.1 million enacted in FY 08. Activities in Advanced capabilities include

[1] As part of the budget restructuring undertaken in the FY 09 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.

- Human research to support ISS and future exploration by investigating and mitigating risks to astronaut health and developing human spaceflight medical and human factors standards;
- Exploration Technology Development to support Orion and other exploration programs. Requested funding in FY 09 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 FY 08. 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 services 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

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

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 steppingstones 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 overdesigned 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.

<u>Status of Key Exploration Systems Initiatives and the "Gap"</u>

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 FY 07 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 5 years in U.S. spaceflight capability due to the retirement of the shuttle in 2010. The confidence level set by NASA of achieving the March 2015 date is 65%.

The FY 09 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 FY 09 budget request does not accelerate the initial operating capability date. This issue was brought up recently at the NASA FY 09 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 FY 09 and FY 10.

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 FY 09. 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 FY 10 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 8 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 FY 09 is $56.3 million, a significant decrease from the $198.2 enacted in FY08. The bulk of LPRP funding occurred in FY 07 ($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 7 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 predeployed 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 7 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 spaceflight 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 spaceflight 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. policymakers approved a spaceflight 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 spaceflight 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, proactively 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 spaceflight 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. spaceflight 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. Non-recurring 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 overdesigned 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. Duallaunch 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 boiloff 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% 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 spaceflight 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 5-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 5-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.