NASA HUMAN SPACEFLIGHT PAST, PRESENT, AND FUTURE: WHERE DO WE GO FROM HERE?

HEARING

BEFORE THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
HOUSE OF REPRESENTATIVES

ONE HUNDRED TWELFTH CONGRESS

FIRST SESSION

THURSDAY, SEPTEMBER 22, 2011

Serial No. 112–038

Printed for the use of the Committee on Science, Space, and Technology

Available via the World Wide Web: http://science.house.gov

U.S. GOVERNMENT PRINTING OFFICE
68–319PDF WASHINGTON : 2011

For sale by the Superintendent of Documents, U.S. Government Printing Office
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Thursday, September 22, 2011

NASA HUMAN SPACEFLIGHT PAST, PRESENT, AND FUTURE: WHERE DO WE GO FROM HERE?

THURSDAY, SEPTEMBER 22, 2011

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

The Committee met, pursuant to call, at 10:10 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Ralph M. Hall [Chairman of the Committee] presiding.

U.S. HOUSE OF REPRESENTATIVES

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

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NASA Human Spaceflight Past, Present, and Future: Where Do We Go From Here?

Thursday, September 22, 2011

10:00 a.m.-12:00 p.m.

2318 Rayburn House Office Building

Witnesses

Mr. Neil A. Armstrong
Commander, Apollo 11

Captain Eugene A. Cernan USN (ret.)
Commander, Apollo 17

Dr. Maria Zuber
E.A. Griswold Professor of Geophysics and Head of the Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology

Dr. Michael D. Griffin
Eminent Scholar and Professor, Mechanical and Aerospace Engineering, University of Alabama in Huntsville

HEARING CHARTER

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

NASA Human Spaceflight Past, Present, and Future:
Where Do We Go From Here?

THURSDAY, SEPTEMBER 22, 2011
10:00 A.M.—12:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING
OVERFLOW ROOM: 2237 RAYBURN HOUSE OFFICE BLDG

Purpose

The hearing will examine (1) the strategic goals and priorities of America's human space exploration program, (2) the importance of space access and demonstrated leadership among space-faring nations, (3) the inspirational role of human and robotic space exploration, and (4) the role of the Space Launch System and Multi-Purpose Crew Vehicle and a healthy industrial base in achieving those goals. The hearing draws on our Nation's long history of space exploration to help frame challenges confronting our present human spaceflight position and explores paths forward.

Witnesses

- **Mr. Neil A. Armstrong**, Commander, Apollo 11
- **Captain Eugene A. Cernan USN (ret.)**, Commander, Apollo 17
- **Dr. Maria Zuber**, E.A. Griswold Professor of Geophysics and Head of the Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology
- **Dr. Michael D. Griffin**, Eminent Scholar and Professor, Mechanical and Aerospace Engineering, University of Alabama in Huntsville

Overarching Issues and Questions

With the retirement of the Space Shuttle, America's human spaceflight program faces a transition. Congress, the Administration and industry are exploring paths forward within current fiscal constraints. Coupled with that is the desire to take on new challenges in deep space and keep ahead of other space faring nations who also share ambitions for deep space missions.

As our Nation embarks on a new path forward, key questions remain: What are the compelling reasons to pursue human space exploration? How is our stature as a world power affected if the U.S. is not active on the human space frontier when others are? What is the effect on our national security if the U.S. is no longer regarded as a preeminent world power? What destinations should be pursued, and has NASA selected the right vehicle architecture for a successful program? Have the Administration and Congress allotted the appropriate resources to accomplish our national objectives?

In 2009, the National Academy of Sciences Committee on the Rationale and Goals of the U.S. Civil Space Program explored many of these broad issues and made the following recommendations:

NASA should be on the leading edge of actively pursuing human spaceflight, to extend the human experience into new frontiers, challenge technology, bring global prestige, and excite the public's imagination. These goals should be accomplished by:

- Setting challenging objectives that advance the frontier, scientific and technological understanding, and the state of the art;
- Establishing clear goals for each step in a sequence of human spaceflight missions beyond low Earth orbit that will develop techniques and hardware that can be used in a next step further outward;
- Focusing use of the ISS on advancing capabilities for human space exploration;

- Using human spaceflight to enhance the U.S. soft power leadership by inviting emerging economic powers to join with us in human spaceflight adventures.

The hearing is an opportunity to consider a logical path forward for NASA, and discuss next steps, destinations and capabilities, and the resources and policies needed to achieve them.

Background

The Bush Administration and the NASA Authorization Acts of 2005 and 2008

In the aftermath of the Space Shuttle *Columbia* accident, the Bush Administration proposed a new vision for space exploration which would extend human capabilities beyond low Earth orbit for the first time since 1972. In the NASA Authorization Act of 2005 Congress 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 United States preeminence in space, and as a stepping-stone to future exploration of Mars and other destinations."* [P.L. 109–155]

Subsequently, NASA created the Constellation program consisting of the Ares 1 rocket and Orion crew capsule, the Ares 5 heavy lift launcher, and the Altair lunar lander. Constellation was designed to accommodate this stepping-stone approach, and was Congressionally authorized by the NASA Authorization Act of 2008 *"to ensure that activities in its lunar exploration program shall be designed and implemented in a manner that gives strong consideration to how those activities might also help meet the requirements of future activities beyond the Moon"* and a range of future destinations *"to expand human and robotic presence into the solar system, including the exploration and utilization of the Moon, near Earth asteroids, Lagrangian points, and eventually Mars and its moons."* [P.L. 110–422]

The Obama Administration

Initially the Obama Administration retained the Congressionally authorized policy of returning Americans to the Moon, noting in NASA's FY 2010 budget request that *"Funds freed from the Shuttle's retirement will enable the Agency to support development of systems to deliver people and cargo to the International Space Station and the Moon,"* and, *"The Agency will create a new chapter of this legacy as it works to return Americans to the Moon by 2020 as part of a robust human and robotic space exploration program."* Yet in spite of these assertions, the Administration's FY 2010 budget eliminated funding for the continued development of the Altair lunar lander and the Ares 5 heavy-lift launch vehicle, and cut more than $3 billion from NASA's five-year Exploration Systems budget (relative to the FY 2009 budget request).

Concurrent with the FY 2010 budget proposal, the Administration established an independent review committee chaired by retired Lockheed Martin executive Norman Augustine. *The Review of Human Spaceflight Plans Committee* delivered its final report in October 2009 with the overarching conclusion that *"Meaningful exploration beyond low-Earth orbit is not viable under the FY 2010 budget guideline"* but that *"Meaningful human exploration is possible under a less-constrained budget, increasing annual expenditures by approximately $3 billion in real purchasing power above the FY 2010 guidance."*

Despite the Augustine Committee's finding that the FY 2010 budget profile was insufficient for meaningful human space exploration, the next year the Administration reduced the FY 2011 Exploration Systems budget to $4.3 billion, which was $1.8 billion below the FY 2010 runout plan.

Subsequently, in NASA's FY 2011 budget request, the Administration proposed canceling the *Constellation* program, claiming it was *"trying to recreate the glories of the past with the technologies of the past."* At a speech at the Kennedy Space Center on April 15, 2010, the President said that with respect to the Moon, *"the simple fact is, we have been there before. There is a lot more of space to explore . . . "* He announced that the U.S. would send humans to an asteroid by 2025, followed by a human mission to orbit Mars by the mid-2030s.

With the abrupt cancelation of Constellation, the Administration's FY 2011 budget sought to fund development of "commercial crew" transportation services (three or four, according to NASA) and postpone construction of human exploration systems for at least five years. Instead the Administration proposed an exploration technology development program and deferred any future launch vehicle decisions until no earlier than 2015. Furthermore, the Administration seemed to exclude the Moon as a future destination, but mentioned visiting an unidentified asteroid in 2025 and orbiting Mars in the mid-2030s.

Neither the Administration nor NASA provided Congress with any plans or programs to accomplish those goals. In fact, the funding available for human space exploration in the Administration's FY 2011 budget request was essentially the same as the FY 2010 budget that was deemed "not viable" by the Augustine committee just months earlier.

If one compares the FY 2011 budget plan and outyear funding profile with that of the Augustine committee's "less constrained" budget, the Administration proposed plan through 2025 (the date of the asteroid mission) is $47 billion less than what the Augustine committee deemed necessary to make any exploration options viable. As a result, after extensive review and debate, Congress in its 2010 NASA Authorization Act reversed the Administration's approach and directed the agency to build upon the capabilities of the Shuttle and Constellation programs and immediately begin developing the SLS and MPCV. The SLS and MPCV were to continue developing the advanced human safety features of the Orion project, and be capable of evolving into a heavy lift launch system that could eventually carry 130 tons to orbit to enable human exploration beyond Earth orbit. Congress did not endeavor to define a full-up exploration program. Rather, the goal was to keep alive development of critical hardware—the SLS and MPCV—that would enable NASA to undertake an eventual deep space exploration program once a destination, schedule, and resources had been agreed to.

The NASA Authorization Act of 2010 [P.L. 111–267]

Last year Congress passed the NASA Authorization Act of 2010, which was signed by the President on October 11, 2010 [P.L. 111–267]. The Act provided policy guidance and recommended funding levels for three years, and called for a National Academy *"review of the goals, core capabilities, and direction of human space flight, using the goals set forth in the National Aeronautics and Space Act of 1958, the NASA Authorization Act of 2005, and the NASA Authorization Act of 2008, the goals set forth in this Act, and goals set forth in any existing statement of space policy issued by the President."* The review is to be completed by next year.

Congress again reaffirmed the policy of the NASA Authorization Act of 2005 (42 U.S.C. 16761(a)), *"that the United States shall maintain an uninterrupted capability for human space flight and operations in low-Earth orbit, and beyond, as an essential instrument of national security and of the capacity to ensure continued United States participation and leadership in the exploration and utilization of space."* [§201(b)]

Section 202 (a) stated that *"The long-term goal of the human space flight and exploration efforts of NASA shall* **be to expand permanent human presence beyond low-Earth orbit** and to do so, where practical, in a manner involving international partners." Section 301(a)(1) stated, *"The extension of the human presence from low-Earth orbit to other regions of space beyond low-Earth orbit will enable missions to the surface of the Moon and missions to deep space destinations such as near-Earth asteroids and Mars."*

Section 2(9) of the NASA Authorization Act of 2010 states, *"While commercial transportation systems have the promise to contribute valuable services, it is in the United States' national interest to maintain a government operated space transportation system for crew and cargo delivery to space."*

As a result, **$10.8 billion** was authorized through FY 2013 for the continued development of a Shuttle- and Constellation-derived heavy lift launch system (the Space Launch System and Multipurpose Crew Vehicle) to enable human exploration beyond low Earth orbit. NASA was directed to proceed immediately, and told to modify existing Shuttle and Constellation contracts with the goal of making the system operational by 2016, and ensure a national *"capability to serve as a backup system for supplying and supporting ISS cargo requirements or crew delivery requirements not otherwise met by available commercial or partner-supplied vehicles."* [§302(c)(1)(D)]

Even though the Space Shuttle has been retired, the U.S. still has the responsibility of providing crew transportation to the International Space Station for both NASA and our international partners (other than the Russians). The importance of ensuring the development of a national "backup" system has only grown with delays in commercial cargo demonstration flights and the recent loss of the Russian Progress vehicle on a Soyuz rocket.

Last Wednesday, September 14, 2011, the Administration and NASA announced plans to build the Space Launch System (SLS). The SLS, together with the Orion Multipurpose Crew Vehicle (MPCV), are intended to give NASA the capability to explore space beyond low-Earth orbit—a capability the U.S. has not had since 1972—and provide access to the International Space Station if commercial entities or our international partners cannot do the job.

FY 2011 Full-Year Continuing Resolution

On April 15, 2011, a full-year Continuing Resolution established spending levels for the balance of FY 2011. As noted in the table below, for the Space Launch System, amounts provided are slightly above authorized levels. Subsequently, on June 15, NASA provided Congress with an operating plan based on the Continuing Resolution (FY 11 CR column below) and gave notice that *"(A)dditional information on NASA's progress in selecting an architecture and acquisition strategy will be provided to Congress in the Updated Report on MPCV and SLS in summer 2011."* As noted earlier, NASA announced on September 14 that it was moving forward with the development of the SLS.

NASA FY12 Budget Req - Space Launch System & Multi Purpose Crew Vehicle

($ = million)

	FY11		FY12			FY13	
	Auth	CR	Auth	Budg Req	CJS Appro*	Auth	Budg Req
Space Launch Sys	1.631	1.786	2.650	1.690	1.985	2.640	**
Multi Purpose Crew Veh	1.120	1.196	1.400	0.916	1.063	1.400	**
Total	**$2.751**	**$2.982**	**$4.050**	**$2.606**	**$3.048**	**$2.640**	**$2.591****

*As approved by the CJS Subcommittee on July 7.

** Budget provided no breakout.

Recent FY 2012 Appropriation Activity

On July 7, the House Appropriations Subcommittee on Commerce, Justice, Science, and Related Agencies reported a FY 2012 appropriations bill providing a total of $3.65 billion for Exploration Systems that included the following provision: *"Provided, that not less than $1,063,000,000 shall be for the multipurpose crew vehicle to continue existing vehicle development activities to meet the requirements described in paragraph (a)(1) of section 303 of Public Law 111–267, and not less than $1,985,000,000 shall be for the heavy lift launch vehicle system which shall have a lift capability not less than 130 tons and which shall have an upper stage and other core elements developed simultaneously."*

On September 15, the Senate Appropriations Subcommittee on Commerce, Justice, Science and Related Agencies reported a FY 2012 appropriations bill providing a total of $3.775 billion for Exploration Systems, including $1.2 billion for the Orion Multipurpose Crew vehicle, and $1.8 billion for the heavy lift launch Space Launch System. The Committee provided specific direction into the development of the SLS requiring initial human capability by 2017, the use of fixed-price contracts wherever possible, and imposing a strict cost cap of $11,500,000,000 through fiscal year 2017. Likewise, direction was provided for the Orion Multipurpose Crew Vehicle such that it should be developed as an alternative access to low Earth orbit, including the ISS, by fiscal year 2014, use fixed-price contracts wherever possible, and should be managed under a strict cost cap of $5,500,000,000 through fiscal year 2017.

Chairman HALL. All right. The Committee on Science, Space, and Technology will come to order and say good morning to all of you and welcome to this hearing entitled "NASA Human Spaceflight Past, Present, and Future: Where Do We Go From Here?" In front of you are packets containing the written testimony, biographies, and truth-in-testimony disclosures for today's witnesses. I recognize myself for five minutes for an opening statement.

I would like to welcome everyone here today to discuss America's Human Space Exploration Program, and the vision, goals, resources, hardware, and commitment that go into it. It is hard to imagine a more qualified panel of witnesses with more personal insight and pertinent experience than the ones we have here today. I would like to sincerely thank all of you for taking the time out of your very busy and important schedules to be here and share with this Congress and this Committee your wisdom and your insight that is gained through considerable and unbelievable first-hand experience. We are truly honored to have you here.

NASA's Human Space Exploration Program is fundamental to the Agency's mission and identity. It is synonymous with the image of American leadership, all around the world. The Mercury, Gemini, Apollo, and more recently, Space Shuttle and Space Station programs have had a profound and lasting beneficial effect on our country. They have defined NASA and the spirit and technological prowess of America in the eyes of other nations that few of us in this room can really appreciate. For an agency with a budget that consumes less than 1/2 of one percent of federal spending, and human space exploration is about 20 percent of that, NASA is renowned at home and around the world as an American enterprise whose feats no one has been able to duplicate. To be sure, Russia was the first into space and the first to orbit a human, but after that, no other country had the commitment, resources, technical expertise, and capability to land men on the Moon or to fly a reusable fleet of spaceplanes.

And we are now at a crossroad. The 30-year-old Shuttle program has been retired; the International Space Station is built; and for the next several years, our country is without any domestic capability of getting American astronauts to and from our own space station.

Last fall, after more than a year of protracted debate, the Administration and Congress came to an agreement allowing NASA to proceed with its plan to seed development of a commercial launch industry to take crew to and from low Earth orbit. But the central tenet was agreement to build a Space Launch System and Multi-purpose Crew Vehicle to ensure a future capability to take astronauts into deep space. While Congress and the Administration concurred on these two initiatives, there continues to be differences over resources and schedules that will guide these new programs, and with respect to deep space, we still don't have a destination, which is an important consideration.

Last week, NASA announced plans to proceed with the development of a new heavy lift launch system that will enable our deep space program. Recently released proposals indicate just two flights over the next 10 years. If NASA doesn't move out quickly, more and more of our industrial base, skilled engineers and technicians,

and hard-won capabilities are at risk of withering away. America needs leadership with a compelling vision, and the strength of commitment, or bright young engineers about to enter our workforce will likely look to disciplines other than aerospace if faced with such a protracted development cycle.

I am also concerned that we need a viable backup system to ferry astronauts to and from the International Space Station should commercial crew launch companies not be able to deliver as hoped. It is my sincere hope that NASA, commercial companies, and Congress can work through challenging technical, legal, and regulatory issues in the months and years ahead related to the commercial crew model.

However, as the NASA Authorization Act of 2010 proscribed, we must be ready to service the International Space Station if our hopes of a commercial crew industry are not realized. And just as important, the SLS and other programs begin the work of ensuring that America has an ongoing long-term exploration program.

Today's witnesses are among the best and the brightest in their field——test pilots, astronauts, administrators, and scientists. Collectively, their years of aerospace experience may even exceed my age. I don't know who wrote that part in there, which they are fired. I am 88 and my kids tell me Papa, don't you hate for people to say you are 88? And I tell them that sounds better than don't he look natural? [laughter.] I want to thank them again for agreeing to testify, and I look forward to hearing the benefits of their wisdom and their experience.

And I want to recognize Ms. Johnson for her opening statement.

[The prepared statement of Mr. Hall follows:]

PREPARED STATEMENT OF CHAIRMAN RALPH M. HALL

Good morning. I'd like to welcome everyone here for today's hearing to discuss America's human space exploration program, and the vision, goals, resources, hardware, and commitment that go into it. It is hard to imagine a more qualified panel of witnesses with more personal insight and pertinent experience than the one today. I'd like to sincerely thank all of you for taking time out of your busy schedules to be here and share with this Committee and Congress your wisdom and your insight, gained through considerable first-hand experience.

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I am also concerned that we need a viable backup system to ferry astronauts to and from the ISS should commercial crew launch companies not be able to deliver as hoped. It is my sincere hope that NASA, commercial companies, and Congress can work through challenging technical, legal, and regulatory issues in the months and years ahead related to the nascent commercial crew model. However, as the NASA Authorization Act of 2010 proscribed, we must be ready to service the ISS if our hopes of a commercial crew industry are not realized. And just as importantly, the SLS and MPCV programs begin the work of ensuring that America has an ongoing long-term exploration program.

Today's witnesses are among the best and the brightest in their respective fields; test pilots, astronauts, administrators, and scientists. Collectively, their years of aerospace experience may even exceed my age, which gives me no small comfort. I want to thank them again for agreeing to testify, and I look forward to hearing the benefit of their wisdom and experience.

Ms. JOHNSON. Thank you, Mr. Chairman.

Good morning. I want to join Chairman Hall in welcoming our witnesses. Each of you brings a unique blend of experience, expertise, and accomplishments to today's hearing and I look forward to your testimony. I would also like to take a moment to express my appreciation to Mr. Armstrong and Mr. Cernan for their continued service to the Nation. Their past service as astronauts including commanding Apollo Moon-landing missions, is well known; but what is not so well known is their willingness to continue to serve this country, traveling to war zones and to nations around the world as goodwill ambassadors for America, when they really could be at home enjoying life. But they are giving more time to the country. It shows the type of individuals they are.

I believe it also demonstrates that America's Human Spaceflight Program has always been about much more than simply building rockets and space capsules and launching astronauts into space. It is also about inspiring people, both young and old. It is about providing a peaceful and positive demonstration to nations around the world of American technological preeminence. It is about developing cutting-edge technologies for our human space missions that also benefit our citizens and create new jobs. It is about motivating our young people to pursue careers in science and engineering by providing them with a challenging future that is inherent to space exploration. And it is about advancing our knowledge.

This is so important for our young people. And that is something I think that we in Congress need to remember as we debate what we want to do with our Nation's human spaceflight program. We sometimes forget that the American people are much less interested in what particular rocket NASA will be building than in why we are investing in space exploration in the first place.

As I have always indicated, I think the benefits of investing in human spaceflight are clear and compelling and ones that can justify making a sustained commitment to moving forward on our next steps in exploration. Because that is what we should be talk-

ing about—determining how much we are willing to commit on an annual basis to maintain a credible and forward-looking Human spaceflight and exploration program and not continually revisiting the question of whether we should have one at all. Successive Congresses and Presidents from both parties have already answered that question in the affirmative. It is now time to move on.

That said, I know there will be some who will say the space race is over, we won it more than 40 years ago. And supporters of human space exploration are just captive to nostalgia. Well, I was proud of what this country had accomplished in the Apollo program, but I am not nostalgic about that time. Instead, I support space exploration because it is about the future, not the past.

And I firmly believe we are in a new, equally demanding "space race," a race to inspire our young people to acquire the science and engineering skills they will need to compete for the jobs of the future, a race to develop the technologies that will not only help us explore space but also strengthen our economy and improve our quality of life back here on Earth, and a race to maintain our leadership as a space-faring nation in the face of growing competitive challenges by other nations.

There will also be those who will say it is time to get the government out of space exploration. Let the private sector do it. Such a statement ignores the fact that our Nation's spaceflight program and NASA in total represents one of the most effective public-private partnerships in pursuit of challenging goals that this country has never seen. The facts are clear. Almost 85 percent of NASA's budget already goes to the private sector to provide the hardware, software, intellectual energy, and services that help NASA push back the space frontier.

And, of course, there are those who will say that we should pause our human spaceflight program until we have a clear exploration policy so that NASA doesn't wind up building a "rocket to nowhere." As the Ranking Member of this authorizing Committee, I would only note that three successive NASA Authorizations have directed NASA to pursue a step-by-step program of exploration beyond low Earth orbit. So whether these are called step-by-step or a flexible path exploration program, it is clear that Congress and the President have already given the necessary policy direction. The technical experts at NASA now need to be allowed to get on with the task of developing the specific steps on that path that make the most sense.

And finally, there will be those who will say, "Times are tough. We can't afford it right now." I would respond that we cannot afford not to pursue a meaningful human space program. The amount of funding that will be cut will have no significant positive impact on our fiscal situation, but it will result in the loss of tens of thousands of good-paying jobs, skilled jobs in the aerospace industry. It will slow the development of advanced technologies that could wind up creating new jobs in the future. It will forfeit American leadership in space and will inevitably lead some of our best and brightest young minds to turn away from studying science and engineering. I don't think that makes sense, and I don't think most Americans will either if presented with the facts.

Mr. Chairman, I have shared your frustration at the slow pace with which NASA has been allowed to move on with the human space program, authorized and funded by Congress. And I would note that 16 months ago, the Committee held a similar hearing with Mr. Armstrong and Captain Cernan. At that time, Congresswoman Giffords, who was then Chairwoman of the Space and Aeronautics Subcommittee, voiced her concerns about the viability of the Administration's plans for NASA. Like our witnesses today, she stressed the need for a clear vision, a commitment to consistent, achievable goals, and budgets that are adequate for the task to be undertaken.

Many of the issues raised by Congresswoman Giffords in the past Congress are still relevant today as we look at this year's budget request for NASA. That said, I believe that the President's announcement last week was a very positive step, and I look forward to working with the Members of Congress and the President to help ensure that the Nation can sustain a human spaceflight program it can be proud of for decades to come.

Thank you, and I yield back.

[The prepared statement of Ms. Johnson follows:]

PREPARED STATEMENT OF RANKING MEMBER EDDIE BERNICE JOHNSON

Good morning. I want to join Chairman Hall in welcoming our witnesses. Each of you brings a unique blend of expertise and accomplishments to today's hearing, and I look forward to your testimony. I would also like to take a moment to express my appreciation to Mr. Armstrong and Mr. Cernan for their continued service to this Nation. Their past service as astronauts, including commanding Apollo Moonlanding missions, is well known; what is not so well known is their willingness to *continue* to serve this country, traveling to war zones and to nations around the world as good-will ambassadors for America, when they could be at home enjoying well-earned retirements.

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That is something I think we in Congress need to remember as we debate what we want to do with our Nation's human space flight program. We sometimes forget that the American people are much less interested in *what* particular rocket NASA will be building than in *why* we are investing in space exploration in the first place.

As I have already indicated, I think that the benefits of investing in human space flight are clear and compelling, and ones that can justify making a sustained commitment to moving forward on our next steps in exploration. Because that is what we *should* be talking about—determining how much we are willing to commit on an annual basis to maintain a credible and forward-looking human space flight and exploration program—and not continually revisiting the question of whether we should have one at all. Successive Congresses and Presidents from both parties have already answered that question in the affirmative—it's now time to move on.

That said, I know that there will be some who will say: "The space race is over, we won it more than 40 years ago, and supporters of human space exploration are just captive to nostalgia." Well, I was proud of what this country accomplished in the Apollo program, but I'm not nostalgic for that time. Instead, I support space exploration because it is about the future, not the past.

And I firmly believe we are in a new, equally demanding "space race"—a race to inspire our young people to acquire the science and engineering skills they will need to compete for the jobs of the future; a race to develop the technologies that will not only help us explore space but also strengthen our economy and improve our

quality of life back here on Earth; and a race to maintain our leadership as a spacefaring Nation in the face of growing competitive challenges by other nations.

There will also be those who will say: "It's time to get the government out of space exploration—let the private sector do it." Such a statement ignores the fact that our human space flight program—and NASA in total—represents one of the most effective public-private partnerships in pursuit of challenging goals that this country has ever seen. The facts are c1ear—almost 85% of NASA's budget *already* goes to the private sector to provide the hardware, software, intellectual energy, and services that help NASA push back the space frontier.

And of course there are those who say that we should pause our human space flight program until we have a clear exploration policy, so that NASA doesn't wind up building a "rocket to nowhere." As the Ranking Member of this authorizing Committee, I would only note that three successive NASA Authorizations have directed NASA to pursue a step-by-step program of exploration beyond low Earth orbit. So whether it's called "step-by-step" or a "flexible path" exploration program, it's clear that Congress and the President have already given the necessary policy direction. The technical experts at NASA now need to be allowed to get on with the task of developing the specific steps on that path that make the most sense.

Finally, there will be those who say: "Times are tough. We can't afford it right now." I would respond that we can't afford *not* to pursue a meaningful human space flight program. The amount of funding that would be cut will have no significant positive impact on our fiscal situation, but it will result in the loss of tens of thousands of good-paying, skilled jobs in the aerospace sector; will slow the development of advanced technologies that could wind up creating new jobs in the future; will forfeit American leadership in space; and will inevitably lead some of our best and brightest young minds to turn away from studying science and engineering. I don't think that makes sense, and I don't think most Americans will either if presented with the facts.

Mr. Chairman, I have shared your frustration at the slow pace with which NASA has been allowed to move on with the human space flight program authorized and funded by Congress. I would note that 16 months ago, this Committee held a similar hearing with Mr. Armstrong and Capt. Cernan. At that time, Congresswoman Giffords, who was then Chairwoman of the Space and Aeronautics Subcommittee, voiced her concerns about the viability of the Administration's plans for NASA. Like our witnesses today, she stressed the need for a clear vision, a commitment to consistent, achievable goals, and budgets that are adequate for the tasks to be undertaken.

Many of the issues raised by Congresswoman Giffords in the last Congress are still relevant as we look at this year's budget request for NASA. That said, I believe that the President's announcement last week was a very positive step, and I look forward to working with Members of Congress and the President to help ensure that the Nation can sustain a human space flight program it can be proud of for decades to come.

Thank you, and I yield back the balance of my time.

Chairman HALL. I thank the gentlelady from Texas, who yields back.

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

[The prepared statement of Mr. Costello follows:]

PREPARED STATEMENT OF REPRESENTATIVE JERRY F. COSTELLO

Mr. Chairman, thank you for holding today's hearing to receive testimony on the past, present, and future of the National Aeronautics and Space Administration's (NASA's) human spaceflight programs.

I would like to personally thank Commander Armstrong and Captain Cernan for their defining contributions to the U.S. space program, human spaceflight, and to this Nation. The risks taken and rewards gained from Apollo stand as a testament to the power of human spaceflight to inspire our Nation.

Sixteen months ago, this Committee held a similar hearing with Mr. Armstrong and Capt. Cernan. At that time, Congresswoman Giffords, Chairwoman of the Space and Aeronautics Subcommittee, voiced concern about the viability of the Administration's proposal and the need for budgets that matched the tasks to be undertaken. In her words, you can't do meaningful exploration "on the cheap." She emphasized the need to keep safety paramount while ensuring that the U.S. not cede

its leadership in space and retain an inspiring vision for exploration. Much has changed since that hearing.

The 2010 Authorization Law directed NASA to develop a new government-owned Space Launch System (SLS) and Multi-Purpose Crew Vehicle (MPCV) to explore space beyond low-earth orbit (LEO); provide back-up capability to deliver crew and cargo to the International Space Station (ISS); and preserve the critical skills of our aerospace workforce.

Just over a week ago, NASA announced its final decision for the design of the SLS, and I am pleased that the decision has been made so that we can move forward. Congress needs to examine how the program will be implemented, including the objectives and destinations for human exploration beyond low-Earth orbit.

The inspirational value of human space exploration cannot be underestimated. I am interested in hearing about the potential objectives and destinations for human space exploration that would best maximize the use of the MPCV and SLS while continuing to inspire our Nation.

I welcome our panel of witnesses and look forward to your testimonies. Thank you and I yield back the balance of my time.

Chairman HALL. And I ask unanimous consent that the gentlemen from Texas, Mr. Culberson and Mr. Olson, and Mr. Posey, the gentleman from Florida, be allowed to sit in on the Committee and participate in the hearing. Hearing no objections, it is so ordered.

At this time, I would like to introduce our panel of witnesses. And if I really fully introduced any of them, it would take me the rest of the day, but we have narrowed it down to the height that we absolutely have to introduce you. You all are introduced all the time and the first one that I will introduce, Neil Armstrong, I read the other day where his name is the most recognized name in the world. And he says well, that is dangerous. And I asked him [inaudible] what hotel he checked into, under the name John Smith.

But at this time I want to introduce this panel. Our first witness is Mr. Neil Armstrong, world-renowned for his role as Commander of the Apollo 11 mission, the first human to walk on the Moon. Mr. Armstrong began his distinguished career as a naval aviator flying combat missions over Korea. He spent 15 years at NASA, first as an engineer and test pilot, probing the edge of space with an X–15 when the Agency was known as the National Advisory Committee on Aeronautics. He also served as Command Pilot of Gemini 8 and Commander of Apollo 11. Subsequently, he served as a NASA Deputy Associate Administrator for Aeronautics. Leaving NASA, he taught at the University of Cincinnati and has served in several corporate positions.

I want to welcome Mr. Armstrong. We are not only glad to have you join us, we are honored to have you join us. And the blue book on it is that you have five minutes, each of you, but I doubt seriously if there is anybody here that could even take this gavel away from me to gavel you down if you went a little over. So I recognize you, Neil, at this time, and thank you again, personally and from this entire body.

Our second witness is Captain Eugene A. Cernan. Gene Cernan was a Commander of Apollo 17. He was a naval aviator. This is kind of the day for naval aviators, I think. And after moving over to NASA, he flew on three missions, including pilot of Gemini 9 and Commander of Apollo 17. He was the last man to walk on the Moon so far. I don't ever like to hear people say this is the last vote, you know. If they say, "Is this the last vote of today," that is different. He continued his service at NASA in senior management positions and played a prominent role in the Apollo-Soyuz

Mission. He has won a number of distinctions and has worked in the private sector since leaving the Navy and NASA.

Our third witness is Dr. Maria Zuber, E.A. Griswold Profession of Geophysics at Massachusetts Institute of Technology. She has participated in a number of NASA-sponsored science missions and is currently the Principal Investigator for the GRAIL Mission that launched just two weeks ago. Dr. Zuber also serves as a member of the National Academy of Sciences and a Fellow of the American Geophysical Union and the American Association for the Advancement of Science. Dr. Zuber, it is good to have you appear before us again.

Our final witness for today is Dr. Michael D. Griffin, former NASA Administrator and currently Eminent Scholar and Professor of Mechanical and Aeronautic Aerospace Engineering at the University of Alabama in Huntsville. Mike is well known to many of us, having served as Administrator of NASA from 2005 to 2009, and as head of the Applied Physics Laboratory at Johns Hopkins University. Previously, he held a number of positions in industry and government and he has earned more graduate degrees than anyone I know. I would have to take off my shoes to count the number that he has, including a Ph.D. in aerospace engineering. And Mike, it is good to see you, and if it will help you any, Bart Gordon, the former Chairman, highly recommended you to the President, and he was consistent in not paying any attention to either one of us. Very good to see you again.

I now recognize Captain Cernan to present his testimony. You have written right here Eugene Cernan.

Captain CERNAN. Good morning, Mr. Chairman, Ranking Member——

Chairman HALL. We want Mr. Armstrong and if you fool with me, I will mention I will turn it over to Mr. Griffin here.

Captain CERNAN. I am accustomed to being last [laughter].

Chairman HALL. All right. And I am accustomed to making a few mistakes up here. All right. Honored to have you, Neil. Go ahead. Really. Go ahead and tell us what you want to do.

STATEMENT OF NEIL A. ARMSTRONG, COMMANDER OF APOLLO 11

Mr. ARMSTRONG. Thank you, Mr. Chairman.

At the risk of offending the Ranking Member by talking about the past, I was informed by a gentleman in Australia a couple of months ago of an interesting film that had been created here in the United States that I did not know about. And with your permission, sir, I would show this short film to you.

Chairman HALL. Permission is absolutely granted.

Mr. ARMSTRONG. Thank you, sir.

[Video.]

Mr. ARMSTRONG. This is a confluence of divergent times and disciplines. Forty-two years ago, Apollo 11 landed on the Moon, and this image that you see in front of you shows the last 3–1/2 minutes of what that trajectory looked like over the actual craters that it flew. At the same time, a new technology appeared. This was Google Earth. Some of you have observed your own house on Google Earth. There was a version of this called Google Moon, and

it allowed you to investigate the Moon on your own computer and go where you would like to see.

A gentleman in Georgia, an astronomer by trade, took images from our most recent lunar exploring satellite, the Lunar Reconnaissance Orbiter, which was launched two years ago with very good optics to completely map the surface of the Moon with high-quality images with resolutions of 1/2 to 1 meter. The gentleman took the images from the LRO, the Lunar Reconnaissance Observer, and patched them together using Google Moon. Google Moon allows you to take a perspective of the picture. This picture, the image in front of you is a perspective, but all the images taken by the satellite are vertical, straight down, so Google allows you to take a vertical image and convert it to a perspective, as you see on this image.

The gentleman patched together a myriad of images from different orbits of the LRO that passed over the trajectory of the Apollo 11 descent and recreated the descent in a perspective mode.

The actual descent was 12–1/2 minutes. This is the last 3–1/2 minutes. It starts about 3,000 feet in altitude and continues all the way down to the surface. Let us go to the next slide, please. Okay, stop. On the left side of the screen, you will see the image that was taken by the 16mm movie camera located in a bracket in the right-hand window of the lunar module Eagle. And it shows the picture that has often been used by anyone who made films about what happened on Apollo 11 and the lunar descent.

The right-hand picture is composed of images from LRO in the last two years and recreated the descent. So you see in the right-hand side of the picture an image that accurately reflects what the crew, what we in the lunar module Eagle actually saw while we were going down. So the picture on the left is a rectangle that is skewed at 45 degrees roughly because that is the way it was mounted in the window. And it is partly blocked by structure of the lunar module. So it has a very limited field of view.

The picture on the right shows the same angular area covered by the motion picture on the right. So you can compare the craters—the little crater on the left to the crater on the left—let us see. That crater is the same as this crater here and that crater is the one that is there. And you will be able to see those comparison craters as you go down the trajectory all the way down to the surface.

Okay. So let us start the video. You will hear the sounds of my copilot giving me numbers and you will hear ground control at Houston responding to our actions. We are descending at a rate of about 2,000 feet a minute. We had computer warnings rather frequently but we were continuing to run on autopilot. The autopilot is going to land us close to the rim of that large crater. I don't want to go there. It is a steep side so we are going over a field of large boulders about the size of automobiles, not a good place to land at all. Trying to fly about a mile further to the west and find a smooth and level landing spot. It is more computer alarms but we are getting used to those now. See a crater coming up now on the top of the screen. It is about 30 meters across, about 100 feet, and that is not good. It looks like some little spots beyond that that look good. We are running low on fuel because we have extended our

flight plan, our trajectory past the intended landing spot, but we still have about a minute of fuel left, and we consider that to be adequate.

That is a good-looking crater and I want to go back there and have a look at that if I get a chance later. In fact, I think the landing area is right ahead. It looks pretty good. There are little craters in there but they look manageable, so we are turning down low to the surface and starting to pick up a little dust at this point. You can see that in the left-hand side. And of course, the satellite picture on the right from a few years ago doesn't show that.

We are heading down very low to the surface; the moving dust is increasing. There you see the shadow of our lunar landing leg in the bottom of our spacecraft touching the surface.

What you see here, Mr. Chairman, is one of the actual vertical pictures taken of the spot where we landed. And of course, what you see is the descent stage of the Eagle that contains the rocket engine that we will use for the descent, the fuel for that engine, and the landing legs and some of our scientific equipment, which we left behind on the Moon. So a view into history through the views of modern technology.

Thank you, Mr. Chairman.

Chairman HALL. All of us up here hope you landed just now. I won't count that against your five minutes if you have anything else you want to tell us.

Mr. ARMSTRONG. Thank you, sir.

Chairman Hall, Ranking Member Johnson, Members of the Committee, thank you so much for giving me the invitation and the opportunity to present my perspective on the state of the American human space exploration efforts. This past year has been frustrating for NASA observers as they tried to understand NASA's plans and progress. The NASA leadership enthusiastically assured the American people that the Agency was indeed embarking on an exciting new age of discovery in the cosmos. But the realities of the termination of the Shuttle program, the cancellation of existing launching rocket and spacecraft programs, the layoffs of thousands of aerospace workers, and the outlook for American space activity throughout the next decade was difficult to reconcile with the Agency assertions.

After this initial proposed cancellation of the Constellation Ares launchers and Orion and Altair spacecraft early last year, this Committee and other Representatives, Senators, and concerned citizens worked diligently to find alternatives to the now missing essential elements of the U.S. space strategy.

You were resolute in modifying the Administration's proposed five-year study of heavy lift rockets and changed to the immediate initiation of its design and construction. And you observed the metamorphosis of the canceled Orion first into an ill-conceived Crew Rescue Vehicle and thereafter into a potentially very useful Multipurpose Crew Vehicle. So, much has been accomplished. But NASA, hobbled by cumbrous limitations, has been unable to articulate a master plan that excites the imagination and provides a semblance of predictability to the aerospace industry.

We will have no American access to, nor return from, low Earth orbit and the International Space Station for an unpredictable time

in the future. For a country that has invested so much for so long to achieve a leadership position in space exploration and exploitation, this condition is viewed by many as lamentably embarrassing and unacceptable.

The severe reductions in space activity have caused substantial erosion in many critical technical areas and are creating negative economies of scale cost increases throughout the aerospace industry. Most importantly, public policy must be guided by the recognition that we live in a technology-driven world where progress is rapid and unstoppable. Our choices are to lead, try to keep up, or get out of the way. A lead, however earnestly and expensively won, once lost, is very difficult and expensive to regain.

The key to the success of American investment in space is a clearly articulated plan and strategy supported by the Administration and the Congress and implemented with all the consistency that the vagaries of the budget will allow. Such a program will motivate the young toward excellence, support a vital industry, and earn the respect of the world.

Some significant progress has been achieved during the past year. However, NASA, with insufficient resources, continues to try to fulfill the directives of the Administration and the mandates of the Congress, and the result is a fractious process that satisfies neither. The absence of a comprehensive plan that is understood and supported by government, industry, academia, and society as a whole frustrates everyone. NASA itself, driven with conflicting forces and the dashed hopes of canceled programs, must find ways of restoring hope and confidence to a confused and disconsolate workforce. The reality that there is no requirement for a NASA spacecraft commander for the foreseeable future is obvious and painful to all who have, justifiably, taken great pride in NASA's wondrous space flight achievements of the past half-century.

Winston Churchill famously stated, "Americans will always do the right thing after they have exhausted all the alternatives." And in space fight, we are in the process of exhausting alternatives. I am hopeful that in the near future we will be doing the right thing.

And I thank the Committee very much for giving me this opportunity to thank you for all you do to advance American spaceflight.

[The prepared statement of Mr. Armstrong follows:]

PREPARED STATEMENT OF NEIL A. ARMSTRONG,
COMMANDER, APOLLO 11

Chairman Hall, Ranking Member Johnson, Members of the Committee: Thank you for giving me the opportunity to present my perspective on the state of the American human space exploration efforts. You have provided questions on several specific issues, and I am delighted to respond.

NASA Authorization Act of 2010

The past year has been frustrating to NASA observers, as they tried to understand NASA's plans and progress. The NASA leadership enthusiastically assured the American people that the agency was embarking on an exciting new age of discovery in the cosmos. But the realities of the termination of the Shuttle program, the cancellation of existing rocket launcher and spacecraft programs, the layoffs of thousands of aerospace workers, and the outlook for American space activity throughout the next decade were difficult to reconcile with the agency assertions.

Despite the departures of significant NASA employees, observers knew that the agency still contained many excellent engineers and analysts who would certainly be working diligently to create useful plans and strategies.

After the initial proposed cancellation of the Constellation Ares launchers and Orion and Altair spacecraft, this committee and other Representatives, Senators, and concerned citizens worked diligently to find alternatives for the now-missing essential elements of the U.S. space strategy. You were instrumental in modifying the administration's proposed five-year study of a heavy lift rocket to the immediate initiation of its design and construction. And you observed the metamorphosis of the canceled Orion first into a Crew Rescue vehicle and thereafter into the Multipurpose Crew Vehicle.

So, much has been accomplished. But NASA, hobbled by cumbrous limitations, has been unable to articulate a master plan that excites the imagination and provides a semblance of predictability to the aerospace industry.

We will have no American access to, and return from, low Earth orbit and the International Space Station for an unpredictable length of time in the future. For a country that has invested so much for so long to achieve a leadership position in space exploration and exploitation, this condition is viewed by many as lamentably embarrassing and unacceptable.

NASA, showing some increased flexibility, recently announced that they would assist ATK in the development of the Liberty rocket, which they seemed to have ignored some months ago. This might engender another possible provider of access to low earth orbit and the International Space Station.

Goals and Priorities

There will always be things to do in Low Earth Orbit: Earth observation, imagery and measurement programs, and others, both from the International Space Station and from spacecraft in other orbital inclinations. And some of them can properly be described as exploration. If and when America has available access to LEO, we will be able to fulfill those opportunities.

The larger human exploration goals, however, lie beyond LEO: Luna, the lunar Lagrangian points, Mars and its natural satellites, and Near Earth Objects including meteoroids, comets, and asteroids. Last year I testified to this committee on the rationale for selecting Luna and its environs as the preferred initial option for America's exploration beyond Earth orbit. All that I have learned in the past year has just reinforced that opinion.

Predicting the future is inherently risky, but the proposed Space Launch System (SLS) includes many proven and reliable components, which suggests that its development could be relatively trouble free. If that proves to be so, it would bode well for exploration.

Risks and Challenges for the Aerospace Industry

In order to get a comprehensive perspective on this issue, I asked a number of senior industry leaders for their observations on the matter. This narrative is a compilation of my thoughts and their responses.

The uncertainties associated with the radical changes in space plans and policies of the last two years contributed to a substantial erosion of the United States' historically highly regarded space industrial base. Thousands of jobs have been lost, and the space component of the industry is perceived as unstable, discouraging students from considering preparing themselves for entry into this exciting but demanding career path.

The United States aerospace industry has long enjoyed the reputation of building the best and most advanced aircraft in the world. Consequently, it is the number one contributor to the nation's balance of payments, providing over 50 billion dollars in positive trade balance last year.

Aerospace industry jobs, characteristically, require high skill and provide relatively high compensation. The Aircraft Industry Association reports Aerospace provides more than 600,000 skilled middle-class jobs and the industry supports more than two million middle-class jobs and 30,000 suppliers from all 50 states. NASA and its supporting contractors employ hundreds of thousands of highly skilled engineers and technicians in 44 states

A substantial current and long-range threat is, and will be, the downward trend in engineering degrees granted in this country and the substantial increase in such graduates in other parts of the world. Equally disconcerting are the projections for reductions in individuals grounded in science, technology, engineering, and mathematics, the so-called STEM disciplines. The number of such individuals in other countries is growing rapidly. They become the innovators and are largely responsible for the increasing quantity and quality of new aircraft and spacecraft emerging in foreign lands.

U.S. passengers on regional jets fly almost exclusively foreign aircraft. In 2008 and 2009, over half of U.S. patents were awarded to overseas companies. More than 60 countries are investing in space. China has sent Taikonauts into orbit and tells of their plans to fly to the Moon. India is planning human space flight. Cargo to the International Space Station is flown on Russian, Japanese, or European craft. Americans currently have no access to space on American rockets or in American spacecraft.

The severe reductions in space activity such as the discontinuance of Space Shuttle operations, the cancellation of the Ares rockets, the end of the Minuteman refurbishment programs, the cancellation of the Altair spacecraft and the kinetic energy interceptor, and slowdowns in a variety of related projects have caused substantial erosion in many critical technology areas and are creating negative economies of scale cost increases for both liquid and solid rocket producers.

Most importantly, public policy must be guided by the recognition that we live in a technology-driven world where progress is rapid and unstoppable. Our choices are to lead, to try to keep up, or to get out of the way. A lead, however earnestly and expensively won, once lost, is nearly impossible to regain.

The key to the success of American investment in space exploration is a clearly articulated plan and strategy supported by the Administration and the Congress and implemented with all the consistency that the vagaries of the budget will allow. Such a program will motivate the young toward excellence, support a vital industry, and earn the respect of the world.

Observations and Recommendations

- (a) Above all else, a unified sense of purpose is a principal component necessary for success. It must be more detailed than a vision (a mental image of what the future will or could be like) but not so detailed that it cannot be modified when circumstances dictate. In the Apollo program there was a goal (land a man on the Moon and return him safely to Earth by the end of the decade) that was easily understood by all but gave the participants a great deal of flexibility in determining the preferred methods for its execution.
- (b) America cannot maintain a leadership position without human access to space. After a half century in which American's were being launched into Earth orbit and beyond, Americans find themselves uncertain of when they can reasonably expect our astronauts to travel to the International Space Station or other off-the-Earth destinations in other than a foreign-built and commanded spacecraft.
- Proposals exist for continuing to fly the Space Shuttle under commercial contract. Such proposals should be carefully evaluated prior to allowing them to be rendered "not flightworthy" and their associated ground facilities to be destroyed.
- NASA recently (apparently in a change from their previous position) announced that they were agreeable to assisting a contractor with their proposed "Liberty rocket." This is encouraging as it presents the possibility of another contender for powering the Multipurpose Crew Vehicle or other spacecraft to low Earth Orbit. This proposal should also be carefully evaluated.
- (c) Last year, before this Committee, I briefly described the case for returning to the Moon. During the intervening months, that case has become, if anything, even more compelling. While visiting an asteroid has been discussed for many decades and the value of reducing the threat of near-Earth objects colliding with Earth is unquestioned, the potential value of returning to the Moon is substantially higher. For an informative analysis of the subject, see the Air and Space Web site *http://blogs.airspacemag.com/moon/*.
- (d) Last week, NASA announced their proposal for the new heavy lift vehicle that had been ordered by the Congress in the 2010 Authorization bill. Administrator Bolden announced:
- "This launch vehicle decision is the culmination of a months-long, comprehensive review of potential designs to ensure that the nation gets the best possible rocket for the investment—one that is not only powerful but is also evolvable so it can be adapted to different missions as opportunities arise and new technologies are developed. The rocket will use a liquid hydrogen and liquid oxygen fuel system, where RS–25D/E engines will provide the core propulsion and the J2X engine is planned for use in the upper stage. There will be a full and open competition to develop the boosters based on performance

requirements. Its early flights will be capable of lifting 70–100 metric tons before evolving to a lift capacity of 130 metric tons."

This proposal appears to meet the intent of the Congressional mandate. It is not a revolutionary proposal. The National Space Strategy of the mid-1980s outlined plans to design and build a new expendable heavy booster with the ability to lift 136 metric tons into Earth orbit. In identifying the new rocket as being "evolvable so it can be adapted to different missions as opportunities arise and new technologies are developed," Administrator Bolden make an excellent point. The ability to assemble various rocket stages into a variety of different configurations to meet ever-changing needs is vitally important and often underappreciated.

The Atlas, Titan, Saturn, and Ares rocket families all were able to lift a wide range of payload weights. The Atlas and Atlas Centaur delivered the Mercury Astronauts and many satellites into orbit, the Surveyor to the lunar surface, Mariners to a number of planets, the Viking to Mars, and probes to Jupiter and Saturn. The Titan and Titan series carried the Gemini astronauts and Voyagers to Jupiter, Saturn, and Uranus. The Saturn 1B and V carried the Apollo spacecraft to Earth orbit and the Moon, the Skylab and the Apollo-Soyuz. The Ares series, although limited to only one flight prior to cancellation, showed promise of wide versatility and, because of commonality in design, cost advantages in the larger rocket development program.

As the future rocket family develops, commonality and compatibility characteristics should be paramount in the design process.

Summary

In summary, some significant progress has been achieved during the past year. However, NASA, with insufficient resources, continues to try to fulfill the directives of the Administration and the mandates of the Congress. The result is a fractious process that satisfies neither. The absence of a master plan that is understood and supported by government, industry, academia and society as a whole frustrates everyone. NASA itself, riven by conflicting forces and the dashed hopes of canceled programs, must find ways of restoring hope and confidence to a confused and disconsolate work force. The reality that there is no flight requirement for a NASA pilot-astronaut for the foreseeable future is obvious and painful to all who have, justifiably, taken great pride in NASA's wondrous space flight achievements during the past half century.

Winston Churchill famously stated: "The Americans will always do the right thing after they have exhausted all the alternatives." In space fight, we are in the process of exhausting alternatives. I am hopeful that in the near future, we will be doing the right thing.

I thank the Committee for giving me this opportunity, and thank you for all you do to advance American human space flight.

Chairman HALL. And we thank you very much, each one of us up here. I can't help but tell a story about the 25th anniversary when you were invited to the White House by Mr. Clinton and he left a chair open for you. He didn't expect you there but you showed up. And he was kidding you about not speaking. You got the microphone, you walked over there, and you said the parrot is the only bird in the world that can talk and speak and I can do both. He handed it back to him. The crowd went wild. Thank you again.

All right. At this time, we recognize—I am ready to recognize Eugene Cernan to present his testimony. Gene, good to have you.

STATEMENT OF CAPTAIN EUGENE A. CERNAN, USN (RET.), COMMANDER, APOLLO 17

Captain CERNAN. Thank you—to look at the past, if I may, because I believe it important to go back in time and retrace our path through history to the day from which we were destined to become the world's leading space-faring nation. And as we now look to the future, I consider the past extremely vital so as to fully understand

what is required to become once again the unchallenged leader in a world of space exploration.

And I can only assume, Mr. Chairman, you would give me the same courtesy you gave Neil and not count my first paragraph or two.

Chairman HALL. Are there objections? Chair hears none.

Captain CERNAN. Lest we forget, Mr. Chairman, it was a bold and courageous President over a half-century ago who started us on a journey to the stars, a journey from which America never looked back, and a journey that challenged the American people at every crossroad to do what most at the time thought impossible. It was a challenge that came in what we remember as the "terrible '60s," a time when our Nation was shackled with civil strife, campus unrest, and the beginning of what became a very, very unpopular war. And perhaps foremost, it was a challenge to the then-Soviet Union's dominance in space. To meet that challenge required all the dedication and personal commitment our Nation could muster. And it was not going to be easy, but hard, and did require sacrifice, just as John F. Kennedy said it would. However, being second best was unacceptable then and being just good today is never going to be good enough for the American people.

JFK did not just challenge us to go to the Moon. He believed it was time to take a leading role in space, a role he thought might well hold to the future of us, of our Nation on Earth. So we built upon the uncertainty of Mercury, fabricated Gemini, the bridge to Apollo, and then realized the dream of mankind for eons of time when over 40 years ago we were able to call the Moon our home.

But we did not quit there. Before the end of Apollo in 1972, when those "most recent steps were taken," Skylab, man's first orbiting laboratory, was already ready to fly. The Space Shuttle, perhaps the most capable flying machine ever designed, built, and flown by man, was already on the drawing boards. And today the International Space Station, the assembly of which may well go down in history as man's greatest engineering accomplishment of all time, circles the globe some 14 times a day every day, all in keeping with JFK's challenge to go to the Moon "and do the other things."

Along the way, thousands of young Americans, who were inspired by what was happening around them, became doctors, engineers, teachers, scientists, and even university Presidents, a "stimulus" for education unparalleled in our history. The above constituted a logical progression with the purpose of achieving and then maintaining our position as the world's leader in space exploration. And with it came the development of technology which allowed us to satisfy mankind's insatiable quest for knowledge, all that on that ocean on which we "set sail" a half-century ago.

For 50 years, Mr. Chairman, we were caught up in the inertia of growth, where each day brought new revelations about the unknown. Our curiosity was overwhelmed with more questions than answers. However, today we are on a path of decay. We are seeing the book closed on five decades of accomplishment as the leader in human space exploration. As unimaginable as it seems, we have now come full circle and ceded our leadership role in space back to

the same country, albeit by a different name, that spurred our challenge five decades ago.

What measures are needed to reverse this inertia of today? Based upon history, the long-term solution appears obvious. One only has to look back and learn from history to understand what it will take to once again be the world's leading space-faring nation. We need an administration that believes in and understands the importance of America's commitment to regaining its preeminence in space, an administration which will provide us with a leader who will once again be bold, just as JFK was, and challenge our people to do what history has now told us is possible. We must have a forward-looking independent NASA who can advise the President, manage far-reaching programs, and work with a bipartisan Congress in moving forward with a space program that benefits all Americans. And a NASA that realizes the importance of looking back in history, learning from our mistakes and building upon the successful culture of a government-private industry partnership that has endured throughout the life of our space program developing safe and cost effective space exploration systems.

The short-term solution is far more complex in light of NASA and the present Administration's now obvious—obvious to me anyway—agenda to dismantle a space program that has been five decades in the making. First on this agenda was to cancel Constellation, a $10 billion investment five years in development. Embedded in the Constellation architecture was the culture of a long-range building block that could not only service the ISS, extend the life of Hubble, provide national security, but additionally, would be capable of carrying us back to the Moon and on to Mars. To replace Constellation was a "mission to nowhere" which had no near- or long-term goals, timetable, specific destination, and no direction for human spaceflight, and nowhere were there any specific plans for a design and building of hardware should any part of this agenda be overridden by Congress. Then came a decision to subsidize the commercial space to "whatever extent it might take to make it successful"—a program that appears to have little or no transparency or NASA insight or oversight into existing problems or those that past experience has told us will crop up in the future. My thoughts on commercial space claims are well known. I stand behind my assertion that it will be near the end of the decade before these new entrants will be able to place a human safely and cost effectively in Earth orbit.

Now we have the termination of the Space Shuttle with, until recently, nothing on the Administration's horizon to replace it. It wasn't but a few months ago that we had the most capable operationally proven launch vehicle far into the future giving us unprecedented personal and payload access to low Earth orbit.

Additionally, the Shuttle had the potential of being the catalyst for the assembly and return to Earth of deep space missions resulting in weight and performance advantages. Even if not in the future plans to be the primary lift to low Earth orbit, the Shuttle certainly provided us with a versatile and redundant operational system.

Isn't it ironic, Mr. Chairman, that we find ourselves today with no capability to access the ISS? I believe the Shuttle retirement to

be a poorly thought-out and premature decision. I take no solace in the failure of the last Soyuz booster, but if one examines the recent letter from Dr. Christopher Kraft, the former head of the Johnson Space Center, concerning a letter to the NASA Administrator concerning this and other problematic contingencies, serious questions could be asked. This letter requested only that the decision on Shuttle retirement be reconsidered in light of the fact that there was nothing to take its place for some indeterminate time in the future.

Mr. Chairman, we stand here today at a crossroads. If we abdicate our leadership in space today, not only is human spaceflight and space exploration at risk, but I believe the future of this country and thus the future of our children and grandchildren as well. Now is the time for wiser heads in the Congress of the United States to prevail. Now is the time to override the Administration's pledge to mediocrity. Now is the time to be bold, innovative, and wise in how we invest in the future of America. Now is the time to reestablish our Nation's commitment to excellence.

Mr. Chairman, Ms. Johnson, ladies and gentlemen, it is not just about space. It is about the country. Thank you, sir.

[The prepared statement of Captain Cernan follows:]

PREPARED STATEMENT OF CAPTAIN EUGENE A. CERNAN, USN (RET.), COMMANDER, APOLLO 17

Thank you, Chairman Hall, Ranking Member Johnson, and Members of the Committee for this opportunity to once again express my personal views and concerns over the future of our Nation's space program. In the short time we have available here this morning, I will do my best to adequately address the questions in your letter of invitation.

The Past

Because the theme of this hearing is **"Spaceflight—Past, Present and Future,"** and because as you, Mr. Chairman, suggested that there are some on this Committee who might well be a generation or more removed from Apollo, I choose first to address the past because I believe it important to go back in time and retrace our path through history to the day from which we were destined to become the world's leading space-faring Nation. As we now look to the future, I consider the past vital so as to fully understand what it required to become the unchallenged leader in the world of space exploration.

Lest we forget, Mr. Chairman, it was a bold and courageous President over a half century ago who started us on a journey to the stars—a journey from which America would never look back —and a journey that challenged the American people at every crossroad to do what most thought couldn't be done. It was a challenge that came in the "terrible '60s," at a time when our Nation was shackled by civil strife, campus unrest, and the beginning of what became a very unpopular war—and perhaps foremost, it was a challenge to the then-Soviet Union's dominance in space. To meet that challenge required all the dedication and personal commitment our Nation could muster. And, it was not going to be easy but hard and did require sacrifice, just as John F. Kennedy said it would. However, being second best was unacceptable then and being just good today is never going to be good enough for the American people.

JFK did not just challenge us to go to the Moon—he believed it was time to take a leading role in space—a role he thought might well hold the key to our future on Earth. So we built upon the uncertainty of Mercury, fabricated Gemini, the bridge to Apollo, and then realized the dream of mankind for eons of time when over 40 years ago we were able to call the Moon our home.

But we did not quit there—before the end of Apollo in 1972, Skylab—man's first orbiting laboratory—was ready to fly; the Space Shuttle, perhaps the most capable flying machine ever designed, built, and flown by man, was already on the drawing boards; and today the International Space Station, the assembly of which may well

go down in history as man's greatest engineering accomplishment of all time, circles the globe 16 times every day—all in keeping with JFK's challenge to go to the Moon "and do the other things." Along the way, thousands of young Americans, who, inspired by what was happening around them, became doctors, engineers, teachers, scientists, and even university presidents—a "stimulus" for education unparalleled in our history. The above constituted a logical progression with the purpose of achieving and then maintaining our position as the world's leading space-faring nation. And with it came the development of technology which allowed us to satisfy mankind's insatiable quest for knowledge—all on that ocean on which we "set sail" a half century ago. For 50 years, Mr. Chairman, we were caught up in the inertia of growth, where each day brought new revelations about the unknown—our curiosity was overwhelmed with more questions than answers.

The Present

However, today we are on a path of decay. We are seeing the book closed on five decades of accomplishments as the world's leading space-faring nation. As unimaginable as it seems, we have now come full circle and ceded our leadership role in space back to the same country, albeit with a different name, that spurred our challenge five decades ago.

What measures are needed to reverse this inertia of decay? Based upon history the long-term solution appears obvious. One only has to look back and learn from history to understand what it will take to once again be the world's leading space-faring nation. We eventually need an administration that believes in and understands the importance of America's commitment to regaining its preeminence in space. An administration which will provide us with a leader who will once again be bold and challenge our people to do what history has now told us *is possible*. We must have a forward-looking, independent NASA which can advise the President, manage far-reaching programs, and work with a bi-partisan Congress in moving forward with a space program that benefits all Americans. And a NASA that realizes the importance of looking back in history—learning from our mistakes and building upon the successful culture of a government-private industry partnership that has endured throughout the life of our space program developing safe and cost-effective space exploration systems.

The short-term solution is more complex in light of NASA and the present Administration's now-obvious agenda to dismantle a space program that has been five decades in the making. First on this agenda was to cancel Constellation—a $10 billion investment five years in development. Embedded in the Constellation architecture was the culture of a long-range building block that could not only service the ISS, extend the life of Hubble, provide national security, but additionally would be capable of carrying us back to the Moon and on to Mars. To replace Constellation was a "mission to nowhere" which had no near- or long-term goals, time table, specific destination, and no direction for Human Space flight—and nowhere were there any specific plans for the design and building of hardware should any part of this agenda be overridden by Congress. Then came a decision to subsidize the commercial sector to "whatever extent it might take to make it successful"—a program that appears to have little or no transparency or NASA insight or oversight into existing problems or those that past experience has told us will crop up in the future. My thoughts on the commercial space claims are well-known. I stand behind my assertion that it will be near the end of the decade before these new entrants will be able to place a human safely and cost effectively in Earth orbit.

Now we have the termination of the Space Shuttle with, until recently, nothing on the Administration's horizon to replace it. It wasn't but a few months ago we had the most capable operationally proven launch vehicle available far into the future giving us unprecedented personal and payload access to low Earth orbit. Additionally, the Shuttle had the potential of being the catalyst for the assembly and return to Earth for deep space missions resulting in weight and performance advantages. Even if not in future plans to be the primary lift to LEO, the Shuttle certainly provided us with a versatile and redundant operational system. Isn't it ironic that we find ourselves today with no, zero, capability to access the ISS? I believe the Shuttle retirement to be a poorly thought out and premature decision. I take no solace in the failure of the last Soyuz booster, but if one examines the recent letter from Dr. Chris Kraft to Charlie Bolden concerning this and other problematic contingencies, serious questions could be asked. This letter requested only that the decision on Shuttle retirement be reconsidered in light of the fact that there was nothing to take its place for some indeterminate time in the future. I find it extremely disrespectful that, to my knowledge, Dr. Kraft has never to this date received a response to his personal letter.

Space Launch System (SLS)

Of record is the NASA Authorization Act of 2010 in which the plans were outlined to build a heavy lift vehicle with Congressionally appropriated and authorized required funding. Several independent cost assessments as well as NASA itself verified that the program was technically and financially feasible as planned. Until this past week, NASA had continued to disregard, ignore, and flout the law and the mandate of the Congress while continuing to pursue its own agenda of disabling our Nation's space program. It had become obvious that NASA as directed by the Administration has had no interest in following the law and the mandate of Congress in the development of a heavy lift launch vehicle.

It is only now after mandates, requests, investigations, a subpoena, and a stinging rebuke of the Administration by two very prominent Senators that NASA has retreated on its delaying tactics to move forward with the development of a Space Launch System (SLS). This is certainly good news forced upon the Administration by concerned and wiser members of Congress, but this decision could well leave us hostage to Russia for access to the ISS for some time to come. Is it possible that the Administration's delay tactics in committing to the SLS somehow have their origin in the delays anticipated in commercial space's development of the capability to put a human in LEO in the foreseeable future?? My assessment of NASA's progress in the development of a heavy lift launch system to enable exploration beyond Earth orbit, as well as provide a capability to service the ISS should a commercial market entrant or our international partners become unavailable, is that it has been deceptive, inadequate and to date non-productive.

The Future

Should the development of the SLS go forward as mandated by Congress along with the Orion Spacecraft as just announced by the Administration, I believe we will have the best and perhaps only opportunity within reach to narrow the gap that now exists between the final Shuttle flight and America's capability to regain access to Earth orbit and the ISS. Access to low Earth orbit should be our primary objective in any plans in the evolutionary development of a new versatile lift vehicle with future deep space missions as a follow-on. This, I understand, is the mandate from Congress. Although it is the intent that the "full up" SLS give us the capability of designing a variable set of missions, I firmly believe that the time for a well-thought-out long-term initiative for our Nation's role in space, with or without the SLS System, is long overdue. The "Mission to Somewhere" logically points to the Moon, thereby building the foundation for a voyage to Mars. Unfortunately, it might well be a generation or more before the U.S. once again exerts its influence in Space Exploration beyond Earth orbit. "If we don't know where we are going, we might end up where we are headed." Nevertheless, since we have apparently decided to relegate the final Shuttle to a place in history, it becomes even more imperative that we move forward quickly and confidently on a LEO derivative of the SLS that can satisfy our urgent near-term requirements to access low Earth orbit.

Risks and Challenges

As a consequence of the cancellation of Constellation, the termination of the Space Shuttle, and NASA's continued unwillingness to accede to Congressional mandates, thus causing unnecessary delays over the past two and one-half years, the risks and challenges to NASA and the aerospace community are numerous. My immediate concerns are the deterioration of our technological base, the lack of stability of the NASA budget when considering the present state of the economy, the absence of the Administration's commitment to cooperate with Congress and forge an ambitious program, the question of continued bi-partisan Congressional support, and perhaps the most important risk with lasting effect, is the loss and dismemberment of our skilled workforce.

As a result of these factors, uncertainty and instability abound. Among the thousands of highly educated workers with unique skills developed over generations, once we lose the older, wiser, mature and experienced folks to retirement, who spent in some cases over five decades learning "what they didn't know they didn't know," along with those inspired and enthusiastic young minds of today's generation to other endeavors, inertia takes hold of the downward trend and it is difficult, costly and near impossible to reverse. And those young high school and college students whose dreams were to take their generation back to the Moon and beyond are now questioning their plans to seek studies in science, engineering and math in the future. And for those fortunate few still at work within NASA or its contracting team, without a goal or mission, their future is bleak. Under this cloud of uncertainty,

most are seeking stability for themselves and their families by going elsewhere with their talents. I believe therein is the ongoing risk and challenge this country faces in any potential future development of human space systems. It's important to remember that "technology makes it possible, but people make it happen."

Testimony of May 26, 2010

Very little if anything has changed my assessment of the Administration's space policy since my testimony before this Committee over a year ago. I recounted the words of my colleagues and myself in describing the Administration's plan for the future of Space Exploration—"Devastating," "Slide to mediocrity," "Third-rate stature," "Mission to nowhere." Although with the SLS System we will provide the foundation for designing "missions to somewhere"—they have yet to be defined. So today I stand behind my testimony and convictions of 16 months ago. Nowhere did I find then, nor do I find today, one penny in the FY 2011 budget proposal in support of Space Exploration. Although I do believe and hope that someday they will succeed, I still assess that those entrepreneurs in the world of commercial space who continue their claims of being able to put humans in space in little more than three years for something less than $5 billion, today still "don't yet know what they don't know." My statement that "the sole reliance on the Commercial Sector without a concurrent or back-up approach could very well lead to the abandonment of our $100 billion, 25-year investment in the ISS" is now more prophetic than ever.

"The space program has never been an entitlement, it's an investment in the future—an investment in technology, jobs, international respect and geopolitical leadership and, perhaps most importantly, in the inspiration and education of our youth. Those best and brightest minds at NASA and throughout the multitudes of private contractors, large and small, did not join the team to design windmills or redesign gas pedals, but to live their dreams of once again taking us where no man has gone before. If this Administration's agenda continues to override the mandates of Congress, these technicians, engineers, scientists, a generation removed from Apollo, yet re-inspired by the prospect of going back to the Moon and on to Mars, will be gone—where I don't know—but gone." Sixteen months later, the absence of a well-defined NASA program has already resulted in the loss of thousands of jobs throughout the aerospace industry.

"America's human space flight program has for a half century risen above partisan differences from Eisenhower to Kennedy to the present day. The challenges and accomplishments of the past were those of a nation—never of a political party or of any individual agenda." Proven to be true today by the overwhelming Congressional support and mandates to NASA in support of future space developments.

"We are at a crossroad. If we abdicate our leadership in space today, not only is human spaceflight and space exploration at risk, but I believe the future of this country and thus the future of our children and grandchildren as well. Now is the time for wiser heads in the Congress of the United States to prevail. Now is the time to overrule this Administration's *pledge to mediocrity*. Now is the time to be *bold, innovative* and *wise* in how we invest in the future of America. Now is the time to re-establish our nation's commitment *to excellence*."

Mr. Chairman, Ladies and Gentlemen—**it's not about space—it's about the country**.

Thank you for your time and patience.

Sincerely, and with respect,
Eugene A. Cernan,
Commander, Apollo XVII

Chairman HALL. Thank you very much. Pay no attention to the empty chairs here because we are at a time now when all of us have extra;don't let it indicate a lack of interest on anybody's part, but we all have other things to do. We are kind of in a hard situation here right now. Everything is being taken down. They will be given copies of your testimony and the questions and your answers.

At this time, I recognize Dr. Zuber for her statement.

STATEMENT OF DR. MARIA ZUBER, E.A. GRISWOLD PROFESSOR OF GEOPHYSICS AND HEAD OF THE DEPARTMENT OF EARTH, ATMOSPHERIC AND PLANETARY SCIENCES, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Dr. ZUBER. Great, thank you.

Mr. Chairman, Ranking Member Johnson, and Members of the Committee, thank you for the opportunity to appear today to provide perspectives on the future of human spaceflight. My mission, GRAIL, which is on its way to the Moon, is the first NASA planetary mission which has an imaging experiment with no scientific purpose. It is to be used solely for education targeted at middle school students.

As an educator and a proud participant in NASA's Robotic Exploration Program, I am an enthusiastic supporter of human space exploration. I will focus on a subset of the testimony which addresses the questions that were asked me.

There are two attributes that are necessary for the implementation of a human spaceflight program. First, the program must be managed responsibly with a balance between infusion of new technology and a simple risk-and-cost profile. Unfortunately, NASA's advanced technology work has been cut back, and it is not clear how the Agency will be able to unfold new technologies without a more concentrated effort to develop them. Off-the-shelf technology will not meet all future needs and significant advances will be required if costs are to be managed.

Second, a balanced program of science and technology is necessary. The thought that it is possible to cut out major parts of an industry or a scientific enterprise and that people will return at some undefined point in the future is unsound. There should be a firewall between the human and robotic parts of the space exploration program.

Job one in the next phase of human space flight is to develop reliable, routine access to low Earth orbit. But NASA should be doing the technologically challenging task: transporting humans to unexplored destinations. While it is possible to quibble about details of lift capacity, et cetera, the plan for the Space Launch System announced by Administrator Bolden last week is responsive to this objective, as is the intention to develop a new crew launch vehicle. When the time comes that one or more reliable commercial launch vehicles are available, it is these entities that should transport cargo and ultimately humans to low Earth orbit. Such capabilities will free NASA to focus on exploration beyond Earth orbit.

The ultimate destination for our Human Spaceflight Program should be astronauts on the surface of Mars. However, in the meantime, landing on a planetary body with significant gravity is especially complex and therefore expensive. In the meantime, expeditions to a Lagrange point or to rendezvous with an asteroid would be more straightforward technically to accomplish and would have the advantage of providing much-needed experience for humans to function beyond Earth orbit.

The American public, and by extension NASA, grows ever more risk-averse. Today, I cannot imagine that we would send a mission to the Moon if lightning struck the launch vehicle, as happened

with Apollo 12. In human spaceflight, we require a full understanding of the technology we launch and the environments we traverse. Information returned from NASA's space science missions provides the context on the space environment that will enable future human exploration beyond low Earth orbit. Robotic observations provide information on radiation fluxes in space, surface hazards that jeopardize landings—Apollo 11 being a case in point—and atmospheric variability that will be relevant to landing on Mars. Robotic reconnaissance also provides guidance as to the most interesting areas to explore.

My mission, GRAIL, was selected solely on the basis of its scientific goal of understanding the structure and evolution of the Moon and its ability to advance similar understanding of the rocky planets, including Earth. However, the new understanding of gravity will enable and also provide distinct benefits for future robotic and human exploration. GRAIL will provide a precise gravity field and an accurate latitude/longitude grid that will greatly facilitate orbital navigation, and in addition, enable any future lunar spacecraft to land exactly where desired, thereby reducing risk and maximizing scientific return.

Human exploration will also be an enabler for planetary exploration. While remote activities like antenna deployment and surface traverses can be accomplished remotely, humans could do such activities far more efficiently. The repair of the Hubble Space Telescope is perhaps the most obvious example of humans contributing significantly to the advance of science.

A forward-looking endeavor that would be particularly suited to humans on the surface of another planet would be deep drilling. Imagine exploring below the surface of Mars to search where life retreated there when the planet lost its atmosphere early in its history. Imagine drilling deep into the Moon to understand the role of solar heating over the past several hundred years, an activity that would elucidate the role of the sun in Earth's climate history.

I am grateful for the opportunity to contribute to the national discussion of how to implement a future sustainable human spaceflight program and I look forward to responding to your questions.

[The prepared statement of Dr. Zuber follows:]

PREPARED STATEMENT OF DR. MARIA ZUBER, E.A. GRISWOLD
PROFESSOR OF GEOPHYSICS AND HEAD OF
THE DEPARTMENT OF EARTH, ATMOSPHERIC AND PLANETARY SCIENCES,
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Mr. Chairman and Members of the Committee, thank you for the opportunity to appear today to provide perspectives on the Future of Human Spaceflight. I lead NASA's Gravity Recovery and Interior Laboratory (GRAIL) dual-spacecraft mission to the Moon that lifted off successfully from Cape Canaveral Air Force Station on September 10, 2011. The mission, which launched on spec, on time and under budget, is the first robotic demonstration of precision formation flying around another planetary body. The last time precision formation flying was performed at the Moon was during the Apollo 17 mission under the command of Captain Eugene Cernan. As a space scientist and educator, I am an enthusiastic supporter of the human exploration of space, as detailed in the following testimony.

Rationales for and Benefits of Human Exploration

History teaches us that great civilizations explore and dare not cease exploration. As a case in point, in the early to mid 1400s China had arguably the greatest navy on Earth under the command of Zheng He. During the Ming Dynasty, Chinese expeditions established trade routes in the Indian Ocean to Arabia and Africa, until the voyages were canceled and the fleet was burned, in part to save money. Late in the same century (1497) Vasco da Gama led four small ships around the Cape of Good Hope on first successful expedition from Europe to India. World history may have been very different had da Gama's handful of ships encountered Zheng He's fleet of over 250 large junks. But the Chinese stayed home and their influence waned, while the nations of Western Europe went on to dominate world affairs.

The rationales for human exploration of space are numerous and have been oft articulated, from the practical to the sublime:

- The human space program produces advanced technologies and high-paying jobs. Like some other government programs, it provides considerable economic benefit to many regions of the U.S.; not a cent of the NASA budget has ever been spent in space.
- The human spaceflight program contributes markedly to the viability of a series of our economic sectors. There are numerous commercial, scientific and military interests in space, such as communications, GPS, weather and climate monitoring, intelligence and surveillance that benefit from investments and technological advances made in the human space program. As a space scientist who develops robotic missions, I believe that a significantly reduced human space program would be devastating in terms of technological base needed to design future robotic experiments.

Human space exploration inspires our youth to pursue careers in science and technology. The influential report "Rising Above the Gathering Storm" elucidated eloquently a national imperative for increased education in Science, Technology, Engineering and Math (STEM). Key decision points are early in middle school when children need to decide to take advanced math that leads to calculus and Advanced Placement science courses in high school. Arguments have been made that there are other great challenges, like energy, that will attract our best and brightest students. This is true. But children aren't thinking about energy at early ages—they're inspired by space and dinosaurs. Having served on President Bush's Moon Mars Commission, I spoke to innumerable citizens who ultimately became telecom engineers, biologists and computer scientists because they watched astronauts walk on the Moon.

- Human exploration will contribute to our understanding of the vastness and makeup of the universe, the tenacity of life and the age-old question of whether life exists beyond Earth. In the near term, I look forward to an increased emphasis on scientific inquiry on the International Space Station. I believe that Nobel Prize-caliber discoveries can be made there. Whenever investigation takes place in a new environment, with new sensors, extraordinary discovery is assured.
- Asking whether the human space program is worthwhile is like asking whether the voyages of da Gama, Magellan or Columbus were worthwhile. As for the Chinese, they've rethought their national strategy. Despite pressing social concerns of the present they're not staying at home anymore. They're going to the Moon.

Charting a Viable Path Forward

In light of economic challenges, fiscal responsibility is essential as is the need for sustained forward progress. An important component of a successful program is the articulation of near- and long-term national goals that are non-partisan. I support the recommendation of the Review of Human Spaceflight Plans Committee that the eventual goal should be the human exploration of Mars.

As a university professor who interacts frequently with students at all levels, I can say with confidence that the goal of human exploration of Mars is also the consensus opinion of the next generation who will carry out this challenge. I cannot estimate the number of students who have found their way to me to tell me that they want to help America go to Mars, in many cases wanting to go themselves. On the wall of my office is a picture of Earth taken from the surface of Mars by the Opportunity rover and I remind the students that everything they know and love is on that dot in the sky, and do they still want to go? Of course they do. I

then dutifully explain the challenges—technical, scientific, psychological and political—do they still want to go? They wonder what's wrong with me; of course they do. Never tell a young person that something they want to do is impossible. NASA should do what I do with these students. Start working on those parts of the challenge that are possible to address within the constraints that exist and keep moving forward; when the time is right to start planning a mission to Mars in earnest the starting base of knowledge must be as robust as it can be.

There are two attributes necessary to any implementation plan. First, the program must be managed responsibly, with a balance between infusion of new technology and a sensible risk and cost profile. Unfortunately Congress is cutting back NASA's advanced technology work and it is not clear how the agency will be able to unfold new advanced missions without a more concentrated effort to develop new technologies. "Off the shelf" technology will not meet all future needs and some significant advances will be required if costs are to be managed. Second, a balanced program of science and technology is necessary; the thought that it is possible to cut out major parts of the industry or scientific enterprise and that people will return at some TBD time in the future is unsound.

Job one in the next phase of human spaceflight is to develop reliable, routine access to low Earth orbit. Most of the energy in spaceflight is in getting off the surface of the Earth. NASA should be doing the technically challenging task—transporting humans to unexplored destinations. While it is possible to quibble about details of lift capacity, etc., the plan for the Space Launch System (SLS) announced by Administrator Bolden last week is responsive to this objective, as is the intention to develop a new crew vehicle. When the time comes that one or more reliable commercial launch vehicles are available, these entities should transport cargo, and ultimately humans, to low Earth orbit. Such capabilities would free NASA to focus on exploration beyond Earth orbit.

Landing on a planetary body with significant gravity is especially complex (and therefore expensive) but expeditions to a Lagrange point or to rendezvous with an asteroid would be more straightforward to accomplish, and would have the advantage of providing much needed experience for humans to function beyond Earth orbit. To ultimately explore Mars, humans need to learn to live and work on a planetary body with gravity. New space suits and surface instrumentation will be necessary. Some of this required technology is under preliminary development.

Synergies Between Human and Robotic Exploration

The American public, and by extension NASA, grows ever more risk averse. Today I cannot imagine that we would send a mission to the Moon if lightning struck the launch vehicle, like we did with Apollo 12. In human spaceflight we require a full understanding of the technology we launch and the environments we traverse. Information returned from NASA's space science missions provides the context of the space environment that will enable future human exploration beyond low Earth orbit. Robotic observations provide information on radiation fluxes in space, surface hazards that jeopardize landings (Apollo 11 being a case in point), and atmospheric variability that will be relevant to landing on Mars. Robotic reconnaissance also provides guidance as to the most interesting areas to explore, for example, the detection of pits that that provide access to subterranean lava tubes on the Moon and Mars. One such pit on the flank of the Pavonis Mons volcano on Mars was discovered by seventh graders from Evergreen Middle School, Cottonwood, California, via the Mars Student Imaging Project operated by NASA and Arizona State University.

My mission, GRAIL, will provide a higher-resolution gravity field of the Moon than currently exists for Earth. This mission was selected solely on the basis of its scientific goal of understanding the structure and evolution of the Moon and its ability to advance similar understanding of all the rocky planets including Earth. However, the new understanding of gravity it will enable also provides distinct benefits for future robotic and human exploration on many different missions. Combined with elevation measurements from the altimeter on the Lunar Reconnaissance Orbiter spacecraft that is currently mapping the Moon, GRAIL will provide a precise gravity field and an accurate latitude-longitude grid that will greatly facilitate orbital navigation and in addition enable any future lunar spacecraft to land exactly where desired, thereby reducing risk and maximizing scientific return.

Human exploration will also be an enabler for planetary exploration. While remote activities like antenna deployment and surface traverses can be accomplished remotely, humans could do such activities far more efficiently. The repair of the Hubble Space Telescope is perhaps the most obvious example of humans contributing significantly to the advance of science. My colleague, Steve Squyres, while celebrating the longevity of his Mars Exploration Rovers, has on more than one oc-

casion reflected wistfully of how much more could have been learned if humans and robots were exploring in concert. A human will always be able to adapt a plan when confronted with new or unexpected information.

A forward-looking endeavor that would be particularly suited to humans on another planet would be deep drilling. Imagine exploring below the surface of Mars to search whether life retreated beneath the surface when the planet lost its atmosphere early in its history. Imagine drilling deep into the Moon to understand the role of solar heating over the past several hundred years, an activity that would elucidate the role of the sun in Earth's climate history.

In Closing

The human spaceflight program has been a source of enormous pride, and the achievements and can do-spirit of the employees of NASA and its industrial and academic partners exemplify much of what makes America great.

I am grateful for the opportunity to contribute to the national discussion of how to implement a future sustainable human spaceflight program, and I look forward to responding to your questions.

Chairman HALL. All right, thank you. And at this time, I recognize Dr. Michael Griffin for five minutes to present his testimony. Dr. Griffin? Your microphone.

STATEMENT OF DR. MICHAEL D. GRIFFIN,
EMINENT SCHOLAR AND PROFESSOR,
MECHANICAL AND AEROSPACE ENGINEERING,
UNIVERSITY OF ALABAMA IN HUNTSVILLE

Dr. GRIFFIN. Thank you. At this point, I feel a little bit like Zsa Zsa Gabor's eighth husband. I know what to do; I am not sure how to make it interesting.

Chairman HALL. Your time has expired and so has Zsa Zsa.

Dr. GRIFFIN. Thank you, sir. I am honored to appear before you today to discuss the future of our space program because in this year of space shuttle retirement, the direction of our space program has been much in the news. But despite that, and prior to this hearing, in my opinion the principal issue before us has not yet been addressed. The central issue to be decided by our Nation's leaders at this time is simply this—do we want to have a real space program or not? Based upon our behavior lately, I believe that most people would be forced to conclude that the answer is not. What is a real space program? Well, let us return to NASA's chartering legislation, the Space Act of 1958. In that seminal work, we find, among other things, that "the aeronautical and space activities of the United States shall be conducted so as to contribute materially to the preservation of the role of the United States as a leader in aeronautical and space science and technology and in the application thereof."

Now, today, the United States is dependent upon a foreign power for the most important of those applications—human spaceflight—and our recovery plan, if that is the word for it, is to depend upon certain companies which have yet to show that they can deliver the laundry to the International Space Station, never mind the crew that would wear it. This does not seem like leadership to me. We are simply not living up either to the letter or to the spirit of the Space Act. To paraphrase my friend and colleague, Boeing Commercial Aircraft CEO Jim Albaugh, the current Administration's view of our Nation's future in space offers no dream, no vision, no plan, no budget, and no remorse.

So do we want to have a real space program or not? It has been said today that there is no important question to which space exploration is the answer. I think that is wrong. I think there are many such questions. What is the nature and value of a human future in space? What directions will human society take as a result of opening the space frontier? What social and cultural values will evolve and prevail and how will we influence those developments? How is our stature as a world power affected if we are not active on the human space frontier when others are? What is the affect on our national security if we are not longer regarded as the preeminent world power? Can our Nation remain open, vital, relevant, competitive, and forward-looking in science, technology, culture, and commerce if it turns back from the frontier of its time? To me, these questions are well worth answering and to resolve them requires a national commitment to a human presence in space to define, occupy, extend, and exploit that frontier.

Humans will commit themselves to that purpose. Whether the United States will be a leader in that endeavor is a question which properly confronts us today, and in my view, all else is detail. These truths were recognized in the NASA Authorization Act of 2005 and again in 2008, both of which originated in this Committee. The course that was laid out in those acts does not need to be changed. It needs to be followed. If we do so, the right rocket designs will emerge. If we don't, the rocket design doesn't matter.

Thank you, and I would be happy to answer any questions you might have.

[The prepared statement of Dr. Griffin follows:]

PREPARED STATEMENT OF DR. MICHAEL D. GRIFFIN,
EMINENT SCHOLAR AND PROFESSOR,
MECHANICAL AND AEROSPACE ENGINEERING,
UNIVERSITY OF ALABAMA IN HUNTSVILLE

Chairman Hall, Ranking Member Johnson, and Members of the Committee: I am honored to have been asked to appear before you today to discuss the future of the space program, a matter which we all consider to be of strategic interest to our Nation. It is also very timely. In this year of Space Shuttle retirement, the direction of our Nation's space program has been much in the news. We have witnessed ongoing debate about the details of rocket design, about the supposed utility of fuel depots, about whether and why NASA will conduct a human mission to an asteroid, about whether NASA's human rating requirements are too strict, and about whether new commercial space companies can develop systems to transport cargo and crew to the International Space Station (ISS). It is possible that the Members of this Committee join me in being a bit distracted by all of this, and I think "distracted" is the proper term, because in my opinion the principal issue before us is "none of the above." The issues I outlined above are consequential, but they are not determinative.

The central issue of space policy to be decided by our nation's leaders is simply this: do we want to have a real space program, or not? Based upon our national behavior of late, I believe that most Americans, as well as our partners and competitors abroad, would be forced to conclude that the answer is "not."

What is a "real space program"? Let us return to NASA's chartering legislation, the Space Act of 1958, for guidance. In that seminal work, we find among other things, that:

- "The Congress declares that the general welfare and security of the United States require that adequate provision be made for aeronautical and space activities."

I think this is still true. Does anyone disagree?

Further, "such activities shall be the responsibility of, and shall be directed by, a civilian agency exercising control over aeronautical and space activities sponsored by the United States."

I've read the Space Act carefully many times. It creates the agency to which it refers, and calls it "NASA." The superior wisdom of the Bureau of the Budget, now OMB, was apparently not thought to be required for the purposes of directing our Nation's space program. Somehow, I doubt that this was an oversight on the part of the Act's creators.

Continuing, "the aeronautical and space activities of the United States shall be conducted so as to contribute materially to [numerous goals follow, including ...] ... the preservation of the role of the United States as a leader in aeronautical and space science and technology and in the application thereof ... "

Today, the United States is dependent upon a foreign power for the most important of those "applications," human spaceflight, and our recovery plan, if that is the word for it, is to depend upon certain entrepreneurial companies which have yet to show that they can deliver the laundry to ISS, never mind the crew that would wear it. This behavior does not seem to me to be consistent with preserving our role as a "leader."

So, as I see it, we today are simply not living up to either the letter or the spirit of the Space Act. To paraphrase my friend and colleague, Boeing Commercial Aircraft CEO Jim Albaugh, the current Administration's view of our Nation's future in space offers "no dream, no vision, no plan, no budget, and no remorse."

Should the goals enunciated in the Space Act be changed? Are they obsolete in the world of today? I would say "no"; I would say that this Nation has been incredibly well served by the vision and goals embodied in that Act, and that we should continue to embrace its vision. But this is the policy discussion we must have, not the details of rocket design or whether our next human spaceflight destination is some asteroid. "We the People" will be here to deal with the consequences of such a decision; this Administration will not.

So in that spirit, do we want to have a real space program, or not? I think we must, because there are questions of societal importance that surround the space enterprise. What is the nature and value of a human future in space? What directions will human society take as a result of opening the space frontier? What social and cultural values will evolve and prevail, and how will we influence these developments? How is our stature as a world power affected if we are not active on the human space frontier when others are? What is the effect on our national security, if we are no longer regarded as the preeminent world power? Can our Nation remain open, vital, relevant, competitive and forward-looking in science, technology, culture, and commerce if it turns back from the frontier of its time?

The resolution of these questions requires a national commitment to a human presence in space to define, occupy, extend, and exploit that frontier. Humans will commit themselves to that purpose. Whether the United States will be a leader in that endeavor is the question which properly confronts us today. All else is detail.

What does a real space program look like, and not look like?

A real space program sets and meets stable national strategic goals for leadership on the space frontier by developing, evolving, and preserving national capabilities to operate on that frontier. It does not allow that capability to be held hostage to the good will of other powers, or to the vagaries of a nascent and fragile marketplace.

A real space program may, and indeed should, offer a stable market to be addressed by commercial providers, but it cannot be dependent upon such providers for strategic capabilities. A real space program recognizes that this Nation has interests that rise above the fortunes of individual private contractors, and it protects those interests. The proper role of government is to reward winners, not to pick them, nor to step in as an investor in enterprises which cannot pass the tests that the capital markets impose.

A real space program is grounded in physics, not politics. In stepping outward beyond low Earth orbit and the ISS, a human return to the Moon is the next logical goal from a host of scientific, engineering, operational, and even commercial perspectives. From there, and with the experience thus gained, we should proceed onward to Mars, and should do so in a timely way, else Mars will always be the destination of the future. With the new systems built for those purposes, it will then be both possible and interesting, as an ancillary mission, to visit one or more near-Earth asteroids, and we should do so when opportunity permits. This is a plan which fits the geography of the Solar System in which we live. A real space program would be built around that fact.

These truths were recognized in the NASA Authorization Act of 2005 and again in 2008, both of which were originated by this Committee. The course for this na-

tion's future in space that was laid out in those Acts does not need to be changed, it needs to be followed. We must stay that course. If we do so, the right rocket designs will emerge. If we cannot, the rocket design doesn't matter. Concerning the larger perspective of this hearing, I can thus offer no better counsel to this Committee than the guidance which it has previously issued.

The remainder of my testimony will address specific issues of narrower scope upon which the Committee has asked me to comment.

- 1. What are the biggest risks and challenges facing NASA and our industrial base as the agency oversees development of several new human spaceflight systems?

As best I can determine, NASA itself is actually "overseeing" only two new human spaceflight systems: the Orion multipurpose crew vehicle (MPCV) and the 130-plus metric ton heavy-lift launch vehicle, the so-called Space Launch System. Both of these are intended for future beyond-LEO human exploration, and should serve that purpose well if funding for those efforts can be maintained. It would be helpful if they could be developed in integrated fashion, working as a program toward a given destination, rather than as independent capabilities.

Should commercial human spaceflight capability fail to be realized, or should such service be interrupted for any reason, the SLS and MPCV can also provide backup access to the ISS, though with considerable cost inefficiency, as they are substantially and intentionally overdesigned for that purpose.

NASA appropriations are being used to provide funds in advance of product delivery (i.e., front-end government "investment" in private concerns) for several commercial space launch, cargo, and crew vehicle development enterprises. There are numerous risks inherent to this aspect of the overall program.

The most obvious concern is that limited NASA funds are being spread too broadly across a nascent commercial space industrial base. The ISS crew and cargo market is insufficient by itself to support several commercial providers, and quite possibly even one. Other commercial human spaceflight markets are not immediately apparent. Thus, if the several firms selected to receive funds under the CCDEV–2 program (Boeing, SpaceX, Sierra Nevada, and Blue Origin) should all succeed technically, one wonders how they will be supported thereafter, other than via outright government subsidy.

Indeed, the administration's reliance on so-called "commercial" means of acquiring human space flight capabilities does not withstand a conventional business case analysis. Understanding that commerce remains a consequence of exploration, the elimination of the Moon as the next logical exploration goal makes no sense. As I stated earlier, it is unlikely that the ISS market alone can sustain even a single commercial vendor, and yet there is no clear plan to provide even that market beyond ISS. However, a straightforward economic analysis shows that the market for the cargo resupply of a human outpost on the lunar surface could indeed be sustainable over the longer term when sound business practices are assumed. Thus, the administration's present exploration strategy to bypass the Moon as a near-term human space flight goal impedes the long-term sustainability of the very commercial sector they are trying to cultivate.

Other concerns exist as well, principally associated with the issue of "oversight" that the Committee has identified in this question. Only one of the companies selected for receipt of funds under CCDEV–2 has any prior experience with human spaceflight, or has yet built a rocket that has entered regular service. But as this Committee knows, the development of these capabilities is not being carried out under direct NASA oversight and control. As befits a commercial model, these firms are carrying out their respective developments largely according to their own standards. This would be expected if these were privately funded activities for the purpose of producing a product to be sold in the market for whatever price that market will bear.

Such is not the case here; public funds have been provided in advance of product delivery to meet a government demand, a fact normally accompanied by the requirement for government oversight and control of product design, development, manufacturing, and operational standards. It is in this fashion that the requirement for public responsibility and accountability for the expenditure of public funds is assured. That requirement is absent in the present plan. I personally expect that this state of affairs can continue only until the first accident happens, the first misuse of public funds is revealed, or some other unseemly event occurs. There will then be a public investigation—quite likely led by this very Committee—which will center on the question "where was NASA's oversight of this effort?" The answer when revealed is not likely to be acceptable.

In summary, and in my judgment, the administration's approach to using the power of the government market to help bring about the development of a robust commercial space flight industry has not been well considered. The resulting turmoil when this is plainly seen by all will, without doubt, further impede progress in human spaceflight, and poses a major risk for this nation.

- 2. Given current and projected future agency budgets, can NASA develop and maintain a safe and affordable human space flight capability? Will NASA be able to afford missions beyond low Earth orbit?

I am concerned that with presently planned budgets, NASA cannot in fact do these things. Table 1, below, shows the reason for this concern. This table compares the President's Budget Requests for 2007 and 2012. As shown, some $50 billion has been removed from NASA's human exploration program through 2016 alone. In fact, the administration's cumulative request for human exploration through 2016 is only 38% of the 2007 request, the first such request after the completion of the NASA Exploration Systems Architecture Study. With this plan, the administration has failed to heed its own Commission's recommendations in regard to the amount of funding which was needed for NASA and human space exploration.

Table 1. Human Exploration Presidential Budget Requests ($M)									Cum
	2009	2010	2011	2012	2013	2014	2015	2016	
2007 Request	4500	5055	8775	9500	11000	13000	14000	14200	80030
2012 Request	3506	3626	3706	3949	3949	3949	3949	3949	30581
Reductions	-994	-1429	-5069	-5551	-7051	-9051	-10051	-10251	-49449

To put the numbers in Table 1 in perspective, the Constellation Program had requested a total of about $110 billion in FY 2005 dollars from 2007–2020 to accomplish the first human return to the Moon, which would have placed four astronauts on the lunar surface for a week, approximately four times the capability of the final Apollo mission. (The total cost of the Apollo Program from 1959–73 was approximately $163 billion in FY 2005 dollars.) Important to note is that this level of investment required no dramatic increase in year-to-year spending for NASA, but was based on the projection of stable funding over that 15-year period. Thus, the Constellation plan represented a reasonable next step in capability beyond Apollo, at a funding level that could be accommodated within a stable NASA budget. The present administration's budget request for human space exploration is enormously reduced. It thus seems clear that the present budget request for NASA is insufficient to accomplish any reasonable program of human exploration.

- 3. What measures do you recommend to help ensure that the Nation successfully develops safe and cost-effective human space exploration systems and maintains a leadership position in the world?

Our nation's space program and those who execute it cannot return anything of lasting value without the re-establishment of stable, strategically selected long-term goals. As discussed earlier, the NASA Authorization Act of 2008, which originated in this Committee, offered just such a vision. The principles of that Act, if re-enacted as the law of the land and funded appropriately, would by themselves result in the restoration of U.S. leadership on the space frontier. Specific recommendations follow below.

- NASA should begin development of a crew transportation system for the purpose of taking our astronauts and those of our international partners to and from low Earth orbit. It is inconceivable that our government would place this Nation in the position of depending solely upon either foreign powers or private entities for human access to space. The new Space Launch System (SLS), while it can accomplish this task, is substantially overdesigned for the purpose. It is nonsensical to require the launch of a heavy-lift vehicle for purposes of ISS resupply or for missions such as Hubble servicing and the like. This Nation, through NASA, should pursue a broad range of human spaceflight programs; exploration beyond low Earth orbit is only one of them. When our Nation is held hostage to other entities for basic access to space, something is very wrong.
- Missions to the Moon, asteroids, and Mars require a heavy-lift launch vehicle if they are to be conducted with any semblance of efficiency. The new Space Launch System, while not as capable or cost-effective as the Ares V design

it replaces, is quite similar and is an effective compromise. The Congress should remain vigilant regarding the conduct of this program, as recent events have made it quite clear that the administration does not actually wish to pursue this development.

In summary, I will close on the point with which I began. This nation needs a real space program. That program is inherently about extending human presence out into the Solar System in which we live. The purposes and benefits of this presence can be seen only dimly today, just as our ancestors had trouble seeing value in the New World beyond Virginia tobacco and the fur trade. But the entire history of human development suggests that those benefits will exceed our wildest imagination, and that they will accrue to the society that takes the gamble.

The current NASA program—development of MPCV and SLS—represents the minimum possible investment in rebuilding the capability needed to begin the establishment of a permanent human presence beyond Earth Orbit. That human presence should begin on the Moon, the place with the greatest potential to help bring about a viable commercial space industry, and which can serve as the next strategic destination to keep international partners and competitors focused on the peaceful development of the space frontier.

Thank you. I would be happy to answer any questions you may have.

Postscript: a Comment on Fuel Depots

It is sometimes argued that development of a heavy-lift launch vehicle is unnecessary, that the necessary propellant for beyond-LEO missions can be accumulated in "fuel depots" to be resupplied by smaller commercial launch vehicles. The claims made in support of this architectural approach are difficult to understand. In general, the lowest marginal cost-per-pound for payload to orbit is obtained by using a rocket having the largest possible payload. An architectural approach based upon the use of numerous smaller vehicles to stock a fuel depot is inevitably more expensive on a mission-cost basis than can be obtained by putting the necessary payload up in larger pieces, as with a Saturn 5 class vehicle; i.e., 130 metric tons or larger payload capacity.

When this known inefficiency in the marginal cost of tonnage to orbit delivered by smaller launch vehicles in comparison with larger vehicles is acknowledged, the counterargument is sometimes offered that the use of smaller vehicles and fuel depots obviates the need for a heavy-lift launch vehicle, and that the money thus saved more than offsets that which is spent on the fuel depot and smaller launch vehicles. This may or may not be so, depending upon the economics inherent to any given approach, but the argument in any case ignores a more crucial fact—if NASA does not build a heavy-lifter, then we will not have a heavy-lifter! This matters, because human exploration beyond low Earth orbit imposes requirements of far greater scope than merely lifting propellant to orbit, even if that particular requirement does constitute two-thirds of the burden of raw tonnage to orbit. What is ignored by proponents of propellant depots is that the remaining one-third of the total mass consists of large, complex, heavy, tightly integrated systems whose design and development benefits enormously if they can be launched in one piece, with those pieces as large as possible. This can only be done with a true heavy-lift vehicle, preferably one with the largest possible payload volume as well as payload mass. It is simply the case that in some fields of human endeavor, size does matter. Human space exploration is one of those.

Finally, a fuel depot requires a presently non-existent technology—the ability to maintain cryogenic fuels in the necessary thermodynamic state for very long periods in space without expending excessive amounts of propellant due to heating and subsequent "boil off." This technology is the holy grail of deep-space exploration, because it is necessary for both chemical- and nuclear-powered upper stages. We should by all means pursue it. But to embrace an architectural approach that requires a non-existent technology at the very beginning of beyond-LEO operations is unwise in the extreme.

One has the sense that the primary purpose of fuel depots in some proposed space architectures is to provide a market for companies offering rockets with small- to medium-sized payloads. This approach reverses cause-and-effect. We should be asking how commercial space companies can help accomplish the human exploration program we want to do, rather than asking what kind of human exploration program best suits the needs of commercial space.

Chairman HALL. Thank you, sir. And I thank all of you for your testimony. And I remind our Committee rules, our questions are

limited to five minutes. Excuse me. The Chairman at this time will open the round of questions, and I recognize myself for five minutes. And I join all of you, as all of us up here join you, and those who are not here that are occupied elsewhere with duties are interested in a bright future or some kind of a future for space. And if other nations are going to be there, I want to be there, too. It is important to our national security, it is important to our children, it is important to our allies, it is important to our partners. And NASA has finally announced it is moving forward with a Space Launch System and Multipurpose Crew Vehicle. We need to preserve the scales and capabilities of our aerospace industrial base as much as possible so we don't lose the enormous benefits we have gained.

And I would like to ask all of you what near-term milestones and goals do you think NASA and Congress need to focus on? I hope we can preserve our place with our space station, we can stay active in space, and have a presence in space that we don't have—it looks like we are gradually losing. And still pursue Mars but pursue it with little expenditure and not large expenditures because, ultimately, we want to go to Mars or an asteroid or wherever they say we want to go. But I think we need to concentrate much less on that than we do on preserving our space station and having cargo go up there and have our men and women to go as they have in the past. What do you think about those goals and what are your goals?

Mr. ARMSTRONG. Thank you, sir. Sixteen months ago I reported to this committee that the top three goals should be to first maintain a leadership position in space; the second, to guarantee access to space—to and from space; and third, to have an exploration focus, in that order. And I think that is consistent with what you just said, Mr. Chairman.

Chairman HALL. Thank you. Gene, do you have anything to add to that?

Captain CERNAN. Yes, sir.

Chairman HALL. You surely are not going to differ with the two of us, are you?

Captain CERNAN. No, sir. You know, I am an exploration guy at heart. After having the opportunity to go to the Moon twice, staying home is not good enough for me. But I am a realist also. We will go to the Moon and we will go to Mars, not as quickly or as soon as I had hoped, but to me, the direction is more important than the time of when we go.

I think our most crucial concern at this point in time is the ability just to get back into low Earth orbit. We have $100 billion investment up there and a commitment to our international partners that we cannot keep today because we have given up the capability of the shuttle with nothing to replace it at this point in time. Now, the SLS is great. I just hope that there is a derivative of the SLS that allows us to get humans, Americans, back in space prior to 2018 or 2020. Otherwise, the SLS truly is a vehicle that will someday allow us to go somewhere in space.

Chairman HALL. Dr. Zuber?

Dr. ZUBER. The most important thing is to develop a sense of forward motion, and that means the ability to get off the planet. So

I have gone on record as saying that I believe that Nobel Prize-caliber science is capable of being done on the space station and I hope the opportunity occurs for the kind of science to get done on the space station that will lead to great discoveries because I think it can happen.

But I also believe in getting out of Earth orbit and I do think that getting a heavy launch vehicle is the right step in that direction and that will lead to other great science beyond Earth orbit.

Chairman HALL. Thank you. And that is very well said. And thank you for your testimony. Mike, do you want to zero in on that?

Mr. GRIFFIN. I would like to echo the comment that we first have to be able to get to and from Earth orbit. No one could be more of a supporter of commercial space than I, but I am getting tired of hearing that NASA should be left to work the hard problems. I will remind this Committee that independent of what nation you are talking about, independent of what rocket you are talking about, approximately 1 in 50 times when we launch a rocket, it doesn't work. That is the state of human space technology today. About 1 in 50 times the launch fails. So to me, when we say that NASA should be working the hard problems, well, I think that is a hard problem, and our Nation should secure for itself, independent of commercial capability, the ability to again place our people in orbit and get them back. After that, the next priority is a human expedition to return to the Moon and to stay and I think it should be this Nation's privilege to lead an international partnership back to the Moon just as we did on the space station. Thank you.

Chairman HALL. I thank you. And I have another question but my time has expired. At this time, I recognize Ms. Johnson for five minutes.

Ms. JOHNSON. Thank you very much, Mr. Chairman.

And I did hear the comments about my reference to the past, and let me just say that without our predecessors, we would not have had that past who had that vision. And without us becoming predecessors here with vision, we won't have a future. So that is why my real emphasis is on our future. I fully realize that until we are committed to spending the dollars for research that space exploration brings us, we are sitting waiting for others to pass us by. And I think that is not hard to see if we see what is going on today. I know that the budget is very tight, but is it too tight to look out for our future? That is my concern. I think when it gets too tight to look out for our future, we damn our future, because without vision, people do perish.

I don't think I have to wonder where you are but I do know that unless we inspire our young minds as space exploration has done in the past, we won't have the people. When we cut back, we lose our talent. And when we lose our talent, we don't lose them to the next business or the next state or even the next land. We lose them for the United States and that is a real concern that I have.

So what I would like to hear from you—and I think you have said much of this—but I want all of you to comment specifically on,. how can we proceed with the budget restraints that we do have and keep pace with the rest of the world?

Chairman HALL. Who wants to be second? [laughter.]

Mr. ARMSTRONG. Well, I think the key is having the plan, a master plan that everyone supports and with the plan, then, there can be various design reference missions established to which the industry can respond and NASA can select the most valuable one. And there has to be a good deal of flexibility in the planning of going to new places. In both our Gemini and Apollo program, we changed the mission almost every time. I think that will continue in the future because you have to be flexible and ready to incorporate whatever new changes in the environment dictate and what the needs are. So I certainly support your view and I do think having the plan that everyone agrees to is the key.

Chairman HALL. Mr. Cernan?

Captain CERNAN. Ms. Johnson, you said three things that caught my attention in your opening statement. You talked about a public-private partnership to move forward, which I think is so significantly important. You talked about the fact that we cannot not afford to proceed, which is a most true statement that anyone here in this room can make, including people at this table. But you also are concerned about education and the uncertainty of the workforce, something I spent a great deal of time on in my written testimony because I think that is the real challenge, the real risk. There are other risks. Is the budget going to be ready? Can we get the money? Is Congress going to agree? Is NASA going to perform? The real risk, the real challenge of going forward are those young men and women whose talents we cannot afford to lose. The dreamers whose generation wants to take us back where we belong, and they truly believe that. They did not join NASA to build—design windmills and rebuild brake pedals for some country—some other country. They joined NASA to do something unique and different that their parents and grandparents and aunts and uncles did. And the key to the future are those young people.

The old, wiser, smarter, more mature men and women are now retiring, people who have spent 50 years learning what they didn't know they didn't know. And they are turning that experience over to this new enthusiastic young group. And the question you ask is how do we keep them? And we are losing them in droves right now. I don't have an answer to your question other than we can't afford not to proceed forward. They are going. They are leaving. I know. I have talked to them. That concerns me as a major challenge, Mr. Chairman, you asked us of how we get where we want to go.

Chairman HALL. Dr. Zuber, she doesn't have any more time left. I am going to allot you three minutes.

Dr. ZUBER. Okay. Thank you very much.

It is said often that the Nation faces other challenges that need to be focused upon and one example that is given is energy. I am a faculty member at MIT where we have over 1,800 students in the Energy Club. So energy is at the top of the list of problems that our smart students want to solve. But when students are six, seven, eight years old, they are not thinking about solving the energy crisis. They want to be astronauts. And many, many of the students start out being interested in space, the decision point is in middle school where you need to make the decision to take the

hard math that leads you to calculus and AP science courses in high school, which leads you to science and engineering degrees in college. And that is where the space program provides a great deal of inspiration.

Chairman HALL. I couldn't agree more. For young people, high school and early college, other than prayer, energy is probably the most important word in the dictionary. Thank you for that. Sir?

Dr. GRIFFIN. I don't need to extend our time further. I think the prior witnesses have answered well.

Chairman HALL. Well, the gentlelady did have another minute if you want to give her an answer. She is entitled to it.

Dr. GRIFFIN. I would repeat Captain Cernan's question. How can we afford not to do it? What is the value of U.S. leadership? That is the question to be answered not what the cost is. If the United States fails to lead in space, it is unimaginable to me that we will remain a leader on Earth, and I submit that the cost of that is far higher than the NASA budget many times over.

Ms. JOHNSON. Thank you very much, Mr. Chairman, for allowing him to answer.

Chairman HALL. Thank you. The gentlelady's time has expired. The Chair now recognizes the gentleman from Wisconsin, Mr. Sensenbrenner, for five minutes.

Mr. SENSENBRENNER. Thank you very much, Mr. Chairman. And I think that you are to be commended for calling this very timely hearing because we are at a crossroads. And I think I can answer Gene Cernan's question about how do we keep people in the program and how do we attract new people? And that is giving them something to do. And I don't think that the direction that the Administration has set out gives them something to do that is achievable in the short- or the medium-term.

Now, I was around here sitting in Mr. Hall's place 12 years ago and repeatedly expressed my concern that the seed corn of looking forward past assembling the International Space Station and going the next round was being diverted to pay for the Russian part of the space station that the Russians didn't want to pay for. And that was signed off on by then-Vice President Gore and NASA Administrator Dan Golden. And we are suffering now from the consequences of that decision, which most of the members of this committee on a bipartisan basis at the time very strongly disagreed with.

Now, all of that being said, you know, we are basically trying to make up maybe 12 to 15 years of the consequences of the decision that we had to pay the Russians to do what they refused to do in order to get the station going. So, you know, I agree with the priorities that have been set out, but how do we rekindle the imagination of the American public on space in a very, very tight budget time after 15 years of letting the imagination if not the appropriations go and lay fallow?

And I would like to specifically ask Mr. Armstrong and Captain Cernan how to do it because what we hear now from the President on down is, well, we shouldn't go back to the Moon because we have been there and done that. You have been there and done that and, Gene, you have been there and done it twice. So, you know, the first thing we have got to do is we have got to have a John F.

Kennedy moment because the public backed what Kennedy called for in his address and NASA got the Apollo program done on time—actually early and under budget. So how do we do this? You know, you have been symbols, even before you went to the Moon. You are still symbols looking at the crowd that we have here in the Committee and behind you in the public area of this Committee. Let us know, you know, what we can do to rekindle the American spirit and make this a can-do kind of thing. Because the money will follow if the public supports it.

Mr. ARMSTRONG. You have certainly identified an important issue. The reality is that people can be highly motivated if there is hope. And right now, the sense that I have is too many people, young people, have the view that there is too little going on in the American space effort in the next decade, which they are preparing for, so they turn other directions. And so having something in the pipeline that gives hope to the young people is key. And it is important not only to the young people but the existing people in NASA. I note that in yesterday's Aviation Week there is a quote from the Johnson Space Center Director that says his greatest challenge is the retention of the installations Human Spaceflight expertise in the face of falling budgets and significant personnel issues and losses.

Mr. SENSENBRENNER. Captain Cernan?

Captain CERNAN. Thank you. You know, all young kids, all of us growing up had a dream to be something we didn't think we could be, to do something we didn't think was possible. Neil had a dream. I am sure I had a dream, a dream of flying airplanes. Little did I know that that dream many, many years later would lead me to the Moon. If you could find something today, I talk to a lot of kids from college, high school, right down into my grandkid's fourth grade graduation class, there is enthusiasm out there. There is nothing more that I have found more than aviation and space that excites kids' minds and hearts, that inspires them to dream, to be one of those. Poppy, why can't I do that? Why can't I go to the Moon? You can do that. The kindling is there. We have just got to put a little bit more fire in the pot. We have got to market what we are trying to do.

We need—let me tell you. It is not good enough for these kids to say oh, when I grow up I can get put in a room and I can develop technology to do something with. Or when I grow up I can solve the problems of global warming, which is where some people want to take NASA, quite frankly. That is not going to do it. These kids, this generation, whether they are from four to 24 need something that their generation can make happen. Don't tell me I can't do it. Don't challenge the American people—don't tell them it is not possible because they will make it happen. That is a big order and how do you put that together, I don't know, but we need a mission to somewhere where we can put our fingers on, touch, and say in the year 2022 or 2042—quite frankly, I don't care. I said a minute ago it is the direction that counts, not the time we get there. We can give these kids and these young people something that they can make happen in their generation. I think we are halfway to answering the question.

And I need to say something more to Ms. Johnson that I didn't include about people and young people and the workforce. There is an old saying. Technology makes it possible. People make it happen. It is the only reason Neil and I are sitting here today, the technology was going to come. It is the people who gave us the opportunity to do what we did. And those are the people we have to stimulate and get excited about doing something today.

You know, when we talk about a program in disarray and no destination, those are real facts of life and we got to change that.

Chairman HALL. All right. Gentleman's time has expired. Chair now recognizes Mr. Smith, gentleman from Texas. By the way, the annual Legislative Conference started this morning. There is a large group in town, probably about 20,000 people, so that is where a lot of our people are.

Mr. Smith, I recognize you for five minutes.

Mr. SMITH. Thank you, Mr. Chairman. Mr. Chairman, I would like to address my first question to Mr. Armstrong and Captain Cernan, both Apollo Commanders.

Mr. Armstrong, you mentioned a while ago the three goals: leadership, access, exploration. What I would like to know specifically if you could tell us—and the same goes for Captain Cernan—what can we do specifically to reclaim America's leadership in space exploration, any specific vehicles or missions you want to point to? A minute ago, Dr. Griffin mentioned going back into orbit and back and back to the Moon. Do you have similar priorities or are there other priorities? But what specifically can we do to reclaim our leadership? Mr. Armstrong?

Mr. ARMSTRONG. Thank you. I believe we are committed to the space station. We have commitment with other nations and we must do that. And there is much to be gained from it if we do it properly. Right now, we find ourselves in a box where we are not able to fully man the station, and consequently, we are unable to get very much productivity out of it because with the few people that are there, there is—they have to spend most of their time just keeping the station operating and there is little time for the necessary research that is the productive output of the station. That is unfortunate but true.

Second, I share the goal that the Moon is the most logical return past near Earth orbit and I support that.

Mr. SMITH. Okay. Thank you. Captain Cernan?

Captain CERNAN. Yes, sir. I think the first thing we have to do is prove to the rest of the world we are for real. We are here to stay. We are not going to give up the 50 years of what we became. I said a minute ago we just—it is over, supposedly. And the rest of the world has got a right to feel—I feel that way. We have got to prove to the rest of world we are for real. We have got to first get our tails off the ground and get back into Earth orbit and service the space station that we committed to and service the people who we committed access to that space, too. Get the shuttle out of the garage down there at Kennedy, crank up the motors, put it back in service. You want a launch vehicle today that will service the ISS? We have got it sitting down there. So before we put it in a museum, let us make use—it is in its prime of its life. How can we just put it away? Get us back in space. That is the first thing,

and then, once we get that going again and people out there know that we are still in the race and still going to run, then let us put a long-term program together. Whether it uses the SLS or some other system to get us where we want to go, I don't care. Let us just get into space and then decide where we want to go when we leave Earth orbit, which is vitally important.

Mr. SMITH. Thank you, Captain Cernan.

Dr. Griffin, two questions for you. You have written in the past and I think expressed concerns about the Chinese-manned spaceflight program. Are we in danger of losing our lead? Are the Chinese going ahead of us?

Dr. GRIFFIN. Well, in my opinion, China understands what it takes to be a great power. We have written the script for them. We were not a great power to World War II, and since then, we have been the world's great power. They understand that because we showed them how to do it. They are a near-peer competitor of ours and I would worry very much about the future of this Nation if we were not and if we were not seen by all to be a world leader. And I do not understand how a Nation which when the Chinese can reach the Moon and we cannot, I don't see why any other nation would regard us as a world leader.

Mr. SMITH. Okay. Dr. Griffin, last question. Your written testimony today you mention the lack of a business case for commercial space companies and you mentioned conflicting priorities. What are those conflicting priorities? What are your concerns about the commercial space companies?

Dr. GRIFFIN. Well, I have a number of concerns, the chief one of which is that we have offered to the commercial space companies, which are struggling to get into existence, we have offered them the space station market, but the space station market is small and it is temporary. And as Captain Cernan and Mr. Armstrong have stated many times and I echo them, we need something beyond; we need something more. I firmly believe that with a large enough market, commercial space can be successful initially with cargo and then later on with crew. But there is no business case to invest for the space station market alone. We need to have the lunar base market. If there is no business case, then to keep these companies in business will require direct government subsidy and I am unalterably opposed to direct government subsidy. I am a supporter of commercial space. I am opposed to subsidies.

Mr. SMITH. Okay.

Dr. GRIFFIN. So I can end with that.

Mr. SMITH. Okay. Thank you, Dr. Griffin.

Thank you, Mr. Chairman.

Chairman HALL. Thank you. And I might point out that Norm Augustine recommended from that same table $2 billion a year to several past presidents—3 billion a year. I am just off a billion. Came as close as a woman did to having twins. Don't you agree with that that it is money—we are talking about money, more money when we have less than one percent of the budget? It is outrageous that they don't—that they didn't accommodate us with that extra 3 billion as that committee suggested. We wouldn't be where we are today if they had listened to them.

Next, we recognize Mr. Rohrabacher. Okay. I recognize Mr. Rohrabacher, five minutes.

Mr. ROHRABACHER. Thank you, Mr. Chairman.

First of all, I would like to place in the record a letter that was sent to Members of Congress but was recently passed on by the same organization to Mr. Armstrong. And it is a letter from the—it is called the Students for Exploration and Development of Space. It has 300 signatures of space-related students who are involved with the engineering and space-related activity. I would like to place that into the record, Mr. Chairman, at this point.

Chairman HALL. Without objection.

[The letter can be found in Appendix 2.]

Mr. ROHRABACHER. Mr. Cernan, if you could, I would appreciate you reading this letter because it does express these 300 students who already have committed their lives to training for involvement in space how important commercial space is to their dreams. And the fact is they do not look forward to being government employees or parts of the space bureaucracy but look forward to challenges that they think the private sector will be able to take over and be involved in in the future. And it is a very inspiring letter and I would suggest that.

We have some serious challenges and I believe that unless we take advantage of the commercial space alternative as part of that solution that we will not succeed. And let me just ask a couple questions that lead to that—lead me to that conclusion and that is NASA has just announced a $38 billion program to develop the SLS, okay, new Space Launch System, which will be a heavy launch system. But the immediate challenge that you, Mr. Cernan, have described to us is getting into space now to meet the challenge that we have of servicing the space station and meeting our goals just in the next few years. And $38 billion for a rocket that will not be in any way available until the earliest at 2017 for cargo and 2021 for crew, that $38 billion means that that is draining money every year from the potential that we have of having the short-term goals at least fulfilled.

Budget is a real thing here. We believe in vision and dreams but we have to have real-line budgets or those dreams and visions will never come into reality. And without the commercial space, people who are putting their own money and putting private money into the endeavor of building space transportation systems, we are not going to meet any of those short-term goals that you spoke about.

I would like to think that the shuttle can just pick up all this task and do this. The shuttles—we have had two shuttle crashes. We know that it is vulnerable, and the fact is that the shuttle crashed—Dr. Griffin, how much does it cost per shuttle flight? We are talking about a billion dollars, aren't we?

Dr. GRIFFIN. It depends on how many shuttle flights you do. It costs about $2.4 billion a year or a little less to own the shuttle, just to own it, and it costs about $300 million after that for each successive flight.

Mr. ROHRABACHER. So we are talking about a huge expenditure, and that money is coming from someplace, and if it comes especially from neutering the commercial space program but not giving them a contract to be able to put some private sector money into

meet the public sector contracts, we have done a big disservice to these 300 students who have visions about what they want to do in the next 10 years of their life and they want to be associated with the space program.

So we have got some major decisions here. I really appreciate your testimony of all of you here today, but I think that we all need to work together so we have not only a vision of space but we also have a vision of how we are going to go about it in a practical way that we can meet our budget obligations.

Dr. Griffin, I know that you have been a supporter of commercial space in the past but this idea that commercial space hasn't even shown anything that they can deliver laundry, I don't understand that. It seems to me that we have got a lot of other programs in NASA over the last few years that have been over budget and not on time and cost us a lot and we ended up canceling the program, and it is just a very frustrating thing for us. So thank you very much.

My five minutes is over now. Thank you, Mr. Chairman.

Chairman HALL. We will give Dr. Griffin a chance to answer you if he wants to.

Dr. GRIFFIN. Let me be clear for the record. I am not in support of running programs that go over budget, behind schedule or don't do what they are supposed to do. The government can operate programs and do programs efficiently, as can commercial entities. I think we should strive for that. I am not opposed to the development of commercial space. When a commercial capability is ready to emerge, a government declaration of that fact is not necessary, and in fact, government can't stop it. And when a commercial capability is not ready to emerge, nothing that the government can do will make a business case for something which is commercial that is not ready to emerge.

Chairman HALL. The gentleman's time has expired, unless the gentleman wants to make an answer.

All right. The Chair now recognizes Mr. Neugebauer, the gentleman from Texas.

Mr. NEUGEBAUER. Thank you, Mr. Chairman.

I would make a couple of points, and I certainly appreciate our great witnesses today. You know, there is a lot of debate and discussion about where we go with our space program, and I don't know if this is true or not but somebody told me a number of years ago after President Kennedy set out the goal for our Nation that everywhere you went in NASA was little placards that said "the Moon" because that was the goal and it was the focus and that everything that everybody got up every day and said, "What do we do to advance to the goal of going to the Moon?"

So two questions I have this morning. We don't appear to have a clear goal of where we are going with our space program, and would you recommend ways that we could, you know, bring some kind of consensus of where we are going? And the second piece of discussion is, there are people that say do we really need the manned portion with the technology that we have today, can we do space exploration without using the manned portion of it. And obviously you two gentlemen have participated in the manned portion

of it. Does all of it have to be manned or some of it unmanned, and how does that fit into the overall goal?

Mr. Armstrong, we will start with your reflections.

Mr. ARMSTRONG. There is enormous value in our unmanned programs. Many of them go places where humans will never be able to go, so there is information to be gained and these knowledge-gaining probes are imperative for our continued exploration of space.

But the human program is designed with goals to give our future generations options of how to expand, where to expand, where to survive, how to survive, very big questions of the destiny of our human race, and so I think those kind of questions must be investigated by humans and they cannot be done by unmanned spacecraft.

Captain CERNAN. As Neil said, the unmanned program is vitally important. Everywhere we have been, there have been unmanned programs that have preceded us. There are unmanned programs going on now which precede those who will follow us. So I think they are vitally important.

At one time someone thought the first landing on the Moon would come out the other side, it was nothing but a bunch of gas. Well, there are a lot of things we don't know about that are out there in the universe in which we live, and the unmanned program is vital. The rovers on Mars, the Hubble itself lets our imagination stretch out. But I don't mean to make light of it, but there has never been a ticker-tape parade for a robot.

Neil's name is the most well-known name in the universe—you said that—the word, the universe for a reason. He is a human being. He can come back and tell you what it feels like, what it looks like, what it was like to be there. Lewis and Clark didn't send an empty canoe up the river. And I am not making light of it. Human beings have to follow in the footsteps of everything we can send before, that we send unmanned spacecraft, to make sure we are going to get back so we can share these feelings and thoughts with you.

Going back to one of your first questions, the sign that said "Moon," during Apollo on everybody's door, that was a destination. That was a goal. The goal was to get there before the end of the decade. We were going to get there sometime. When Kennedy said we were going to go to the Moon, he said that three weeks after Alan Shepard went up and came down, 16 minutes of spaceflight experience. We knew beans about going to the Moon. The technology didn't exist. But all the people who were working on this program knew that is where we were going to go and American ingenuity was going to find a way to get there, and a testimonial to that ingenuity to American enterprise is the fact that everyone who went to the Moon including Apollo 13 came back home to talk about it.

Chairman HALL. The gentleman's time has expired. Thank you, Mr. Neugebauer.

The Chair now recognizes the gentleman from Texas, Mr. McCaul.

Mr. MCCAUL. Thank you, Mr. Chairman.

Let me just say what an honor it is to be in the presence of the first man to land on the Moon and the last man to land on the Moon. I have said before, Mr. Armstrong, a thousand years from now, no one will remember anybody in this town, but your name will be known.

Your testimony, Mr. Armstrong, was quite revealing. You said NASA has been unable to articulate a master plan that excites the imagination and provides a semblance of predictability to the aerospace industry, and you went on to say we will have no American access to and return from low Earth orbit and the International Space station for an unpredictable length of time in the future. For a country that has invested so much for so long to achieve a leadership position in space exploration, this condition is viewed by many as lamentably embarrassing and unacceptable.

Captain Cernan, you talked about John Kennedy and his vision, and we have on the wall here "Where there is no vision, the people perish," from Proverbs. I am concerned this Administration, this President has no vision. I am also concerned that the next flag to possibly land on the Moon will not be an American flag but rather a Chinese or a Russian flag, and let us not forget the national security implications that are at stake here, as Dr. Griffin talked about.

So many people ask me—and I have Austin to Houston so I have a lot of jobs and space employees in my district. I have been to that room where mission control took place in 1969. And so many people ask me, you know, we landed on the Moon in 1969, why it has taken so long to go back. Why has it taken so long and why is it important today that we go back to the Moon? And so with that, I would like to recognize you, Mr. Armstrong and Captain Cernan, to answer that question.

Mr. ARMSTRONG. America was reveling in the successes of the Apollo program but after you win a big game, why, there is a letdown, and that was an opportunity for some to say well, maybe, you know, we made a big investment in space exploration, spaceflight, perhaps it is time to reap some rewards, so let us look at Earth for a while, let us begin low Earth orbit and spend a lot of time studying Earth and the environs of Earth and get a great return from this investment, and indeed, that is what we did. The shuttle, one of the most magnificent flying machines ever built, highest technology machines, however, cost more to fly and couldn't fly as often as had been predicted by its designers due to reasons that are completely understandable in retrospect, but it used up a lot of the human spaceflight budget and was an inadequate opportunity to develop the developing follow-on spacecraft that would succeed it, and I think that is the principal cause of the question that you asked.

Mr. MCCAUL. Captain Cernan?

Captain CERNAN. After I came back from the Moon on Apollo 17, I got on my soapbox at Kennedy talking to the people at a homecoming and I said, Apollo 17 was the end, how does it feel to be the tail of the dog, the last one over the fence, and I got up on my soapbox and I said it is not the end, it is just the beginning of a whole new era in the history of mankind, and I truly did believe it. I said we are not going to go back to the Moon, we will be on our way to Mars by the turn of the century. Well, my glass was

half empty for a long time until Constellation came along, and then it became half full, and it gave this country something, I think, to look forward to. It re-inspired those young people to dream. And the dreamers of today are the doers of tomorrow, and if we don't inspire those young kids to dream, there isn't going to be any tomorrow, and that is what I was looking at. That is what it was all about.

I forgot the other half of your question, Congressman, but inspiration of these young kids and a goal for them to put their hands on and look forward to, I think, is what this country needs more than anything else. And I will say it again: I am at a point in my life, Neil and I aren't going to see those next young Americans walk on the Moon, and God help us if they are not Americans, that it is somebody else, or if it is a team of people that is not led by Americans. We are not going to be here. We are going to take the last trip off this Earth long before that happens. That is unfortunate, and I never believed it would be that way, but it will. But I am satisfied with that as long as I know—when I leave this planet, I want to know where we are headed as a Nation. That is my big goal. I just feel so strongly about that, and I feel sometimes helpless other than to share those feelings with ladies and gentlemen like you because I am not making the decision to make it happen. I can only try and get people enthused about pointing themselves in that direction.

Mr. MCCAUL. Let me just say thank you for your service, and thank you for your inspiration to not only Americans but the world. Thank you.

Chairman HALL. The gentleman's time has expired.

The Chair recognizes the lady from Florida, Mrs. Adams, for five minutes.

Mrs. ADAMS. Thank you, Mr. Chairman, and on behalf of the Florida Space Coast and the tens of thousands of men and women who in Florida actually dedicated their lives to advancement of this country's space program, I want to thank all of you for your service.

Dr. Griffin, I am going to go back to a few things that have bothered me since I have been elected here in this august body. I just have a few questions. It is going to be kind of quick because I want to stay within my five minutes, and you can answer yes or no and you don't have to expound if you don't feel the need. But when you were Administrator of NASA, did you or your deputies ever ignore one of the authorization bills?

Dr. GRIFFIN. Not ever.

Mrs. ADAMS. Did you ever get subpoenaed by a House or Senate committee for outright ignoring their request for information?

Dr. GRIFFIN. No, ma'am.

Mrs. ADAMS. Were you or your deputies ever accusing by a Senator of sabotaging a NASA project just because you didn't agree with Congress?

Dr. GRIFFIN. Absolutely not.

Mrs. ADAMS. Did you ever decide to ignore the role or will of Congress when they asked you for plans to implement the next step in President Bush's vision for NASA?

Dr. GRIFFIN. Again, no, ma'am.

Mrs. ADAMS. Can you think of any reason to slow roll a project that has been authorized and demanded by Congress and federal law?

Dr. GRIFFIN. Well, if the chief executive doesn't want to do the project, then logically speaking, they will slow roll it because every two years there is an election and there is a chance to try again whereas if you start the project, it becomes more difficult to cancel it. So if I didn't want to do a project and was a different branch of government, then yes, I might slow roll it. I am not endorsing that. But if you ask me if there is a reason to slow roll it, that would be the reason.

Mrs. ADAMS. So can you think of any reason why it would be acceptable for a NASA Administrator or his or her deputy to ignore Congress?

Dr. GRIFFIN. It is not acceptable. Congress—I remind people frequently that they need to read Article I of the Constitution.

Mrs. ADAMS. Well, as you probably guessed, I am kind of miffed at the fact that NASA has done everything in their power to slow us down. I know there was an authorization bill that was passed before I got here and we are just now learning that they may have come up with a plan for the SLS. So I just was curious in past Administrations how that worked.

Dr. GRIFFIN. Well, ma'am, I would say when you say that the blame falls on NASA, I must with respect disagree. NASA is a federal executive agency and they work for the President, and they must follow the instructions of the President, and so the Administrator really has no choice in this matter.

Mrs. ADAMS. So you believe that he was directed, he or she was directed?

Dr. GRIFFIN. If the Administrator is doing opposite to that which the President desires, then he is mutinous and so therefore one must conclude that the Administrator is doing as the Chief Executive requests.

Mrs. ADAMS. Thank you.

Dr. Zuber, you know, some have argued, and the President specifically, that there is no need for the United States to return back to the Moon. The argument is basically been there, done that, and you have heard that here today from people questioning that logic. Do you agree with this assessment? Do you think there is anything more that landing on the Moon could teach us?

Dr. ZUBER. Okay. So first of all, I say that my mission, GRAIL, which is en route to the Moon, and the two spacecraft will arrive on New Year's Eve and New Year's Day of this year, it is a NASA discovery mission and it was the highest rated proposal of the two dozen proposals submitted, both science and implementation, so the scientific rationale was viewed by the scientific community to be the best among the proposals that were submitted during that round. So the science community feels that there was a compelling reason to return to the Moon.

Mrs. ADAMS. And you also, I assume?

Dr. ZUBER. Obviously. But let me give you an example of one of the many scientific questions that you could answer if you go back to the Moon. If you look at the Moon in a telescope, it is heavily cratered. It was bombarded by all the material that was left over

when the planets formed. Earth used to look like that, but the record isn't preserved on Earth because it has been eroded, subducted. It is not there. The craters aren't there. But Earth was that heavily cratered, and the age of this surface of the Moon at the time that that occurred is about the same time that the first single-celled organisms were arising on Earth. And so by studying the Moon, we can learn about the Moon but we can also learn about the conditions that must have also existed on Earth at the time.

Mrs. ADAMS. So returning to the Moon is not useless then. I appreciate that.

And Captain Cernan, Mr. Armstrong, how do we get NASA to move forward with the solid mission if the authorization bill passed last year and we are just now hearing of an SLS? Is there any way that we encourage them to come forward with a solid mission, a vision, I guess, so that we encourage our young people, our youth to get more involved again?

Captain CERNAN. Boy, that is a tough one. You have to recreate a John F. Kennedy. Whether he was a dreamer or a visionary or politically astute, we will never know. He was probably all three, quite frankly, considering the times. I would like to believe he was a dreamer and a visionary. I will let the politically astute go to history. And you don't try and mandate to an Administration or to NASA to do something. They may do it, but if they don't believe in it, they are going to do just what Mike said. They can slowball it, do a lot of things. You have to have somebody, a commander-in-chief who is giving the orders to move forward to believe and commit himself and understand that this is one of the most important things this Nation can do to maintain its leadership, and if you look at the cost versus other things where we are spending our money, Mike informed last night, 15 cents for every American in the country. Fifteen cents it costs to support NASA's budget.

Dr. GRIFFIN. Fifteen cents per day.

Captain CERNAN. Fifteen cents per day. Fine. You know, no one understands what a half percent of our budget is, but people understand that we are spending more money to feed the cat in this country than it costs me to support the space program. I guarantee you, if you put a little mark on that income tax thing that said would you give 15 cents a day or a dollar or $10 of your tax return to NASA to go back to the Moon, I guarantee you, you would have enough money to go there and back twice. I just believe that. We just don't give our people a chance to express themselves because they don't know what it is for. They don't have that goal, that destination, that thing that is going to excite them and inspire them.

Chairman HALL. The gentlelady's time has expired.

The Chair recognizes Mr. Palazzo, the gentleman from Mississippi.

Mr. PALAZZO. Thank you, Chairman Hall, for holding this hearing today and inviting these distinguished panelists to come talk to us. It is an honor to hear their testimony, and if ever the axiom applied for Congress to listen to the people, well, we just need to listen to you all today.

The cause of exploration takes time and has many stages. I would like to get your opinions based on your years of experience.

Commanders Armstrong and Cernan, based on your experience during the Apollo program in particular, what is the value gained in systems-level ground testing, especially the type of engine work done at Stennis Space Center?

Mr. ARMSTRONG. In preparation for this hearing, I took the opportunity to discuss some of the questions that were provided to us that would be of interest to the committee with the leaders of the industry. They universally said that the cutting-edge programs that typically NASA engendered were one of the most important factors in their moving their industry forward and being competitive on the world stage. They all believe that this was enormously important to them and they were very concerned with the declining amount of programs that they were seeing in the pipeline.

Mr. PALAZZO. Commander Cernan?

Captain CERNAN. I don't want to avoid your question, but I think I answered it a little while ago. Everyone who went to the Moon came home. That is the value of ground testing. That is why we are sending human beings, we are not sending—what was the word—biological specimens, as I heard from the commercial sector.

Mr. PALAZZO. A recent quote was "biological cargo."

Captain CERNAN. You know, don't worry about it, we are biological cargo. That came from the commercial side. I feel a little bit less secure about that statement. You know, I will give you an example real quick. On Apollo 17, the LEM that we were flying was the last LEM that Grumman was ever going to build, design and test, and the guys who were testing, ground testing that vehicle before we went to the Moon, 90 percent of them already had their pink slip, they were done, and they came up to me as a group and said Captain Cernan, don't worry about this LEM, it is the best LEM and most ready LEM and most capable that has ever been lifted off of Kennedy, and by God, they were right. And that goes back to the inspiration of having a goal and motivation. Their goal was to see us succeed and their ground testing made it possible that we did.

Mr. PALAZZO. Thank you, sir.

Dr. Griffin, would you like to comment as well?

Dr. GRIFFIN. Well, I am the youngest engineer on the panel because I am preceded by my two older colleagues. I can only support to the maximum what they say. When we don't test adequately on the ground, we usually find our flaws in flight, and unlike airplanes, with rockets we often don't get it back. As I remind some of my friends from the software industry, in the space business, after a crash we can't reboot. So I think the ground testing is crucial.

I would remind everybody that at the present time, Stennis Space Center is the last place in the country where we can conduct large-scale rocket engine testing. When I was much younger, I tested rocket engines at the rocket propulsion lab at Edwards, and those facilities are now in decline. So this is an industrial base issue, as Captain Cernan has referred to earlier, we need to be extremely careful because our industrial base is eroding before our eyes.

Captain CERNAN. I have to believe that it is just important to Dr. Zuber's profession. She has got too much effort, too much time, too

much money and too much at stake not to do what is right before you find out you missed something.

Dr. ZUBER. We launched a Delta II heavy from Pad 17, and actually I was privileged to go up to the top of tower during the rollback, and we had to scrub the launch a couple of times due to weather, and so by the third time that we went out, I was the only one, aside from the crew, who was up at the top of the tower when we pulled back, and when we pulled it back, we had the rocket in front of us and the guys at the top said can we just sit here and look at it a while because we are closing down this pad after this rocket launches and I believe we are never going to see this sight again.

Mr. PALAZZO. Well, thank you all for your commentary. I believe it was somewhere in one of these hearings that someone said it is better to be frustrated and being grounded instead of being up in the air wishing you were on the ground. So thank you all for your commentary.

I yield back.

Chairman HALL. I thank the gentleman.

At this time mentioning scrubbing some of the liftoffs, we have in the audience Kate Kronmiller, who is a long time with USA. You mentioned the ladies in your presentation. She was with USA. They were the ones that say ten, nine, eight, seven, that saved the lives of those who would have been endangered if they had lifted off. Kate, thank you for all you have done.

The Chair now recognizes Mr. Brooks, the gentleman from Alabama, for five minutes.

Mr. BROOKS. Thank you, Mr. Chairman. It truly is an honor to be in the presence of such an esteemed panel.

This question is directed at each of you who wishes to volunteer a response. In your experience, is a NASA-led and -run human spaceflight program crucial or important to America's national security, and if so, how? Whoever wishes to go first.

Dr. GRIFFIN. Thank you, sir. Well, I think—I am on record. I think that the Congress of 50-some years ago got it right with the Space Act when they created a civilian space agency to lead that effort. It has allowed us to conduct extraordinarily effective partnerships with other nations. In my mind, the greatest value of a civilian human spaceflight organization is its national security value, and I will just take a minute, because that is an odd comment.

The United States is a world superpower. We are a world power, and I think we want to continue to be. And in that role, we have to do hard things. We have to do things that not everyone else in the world wishes we did or likes that we did. It then behooves us as a Nation—and I feel very passionately about this. It behooves us to temper those things that we have to do by proactively looking for things we can do to find common cause with other nations, to bind us in alliances and partnerships for things people like to do.

Now, as especially Gene has said over and over, young folks, even us older folks, love aviation and space. When we do exciting, challenging, frontier-oriented space projects and do them in a leadership role in concert with other nations to do things that they like to do, this binds us to the rest of the world in a way which is only

positive. There is no dark cloud around this particular silver lining, and that in my mind only enhances our security, national security, the security of our values and freedoms and culture in the world, and if every dollar that had ever been spent on NASA in the civil human space program were looked at solely from a national security perspective, A, it would be a round-off error in the DOD budget, and B, it would be worth every penny.

I am sorry to have taken so much time, but thank you.

Mr. BROOKS. Well, I have another follow-up question, but if anyone else would like to add something very quickly——

Captain CERNAN. You have heard in national security, the high ground is most important. In today's world, the high ground is technology. Technology is the high ground, and even more so than the evolution, the development of technology, the space program probably moved technology beyond whatever we imagined it could possibly move and quickly, very quickly. And by the way, we did so without the destruction of hundreds of cities and the loss of millions of lives.

So that is what we need to look at is the evolution of technology, and if we are static, if we sit here and watch other people develop technology, it is going to affect our economy, it is going to affect the marketplace. It is not just going to affect our ability to go into space. It is going to affect our way of life.

Mr. BROOKS. Thank you.

I was reviewing the written testimony of Mr. Armstrong, and one paragraph really jumped off the page at me, and I am going to quote it: "The uncertainties associated with the radical changes in space plans and policies of the last two years contributed to a substantial erosion in United States' historically highly regarded space industrial base. Thousands of jobs have been lost, and the space component of the industry is perceived as unstable, discouraging students from considering preparing themselves for entry into this exciting but demanding career path."

In light of the relationship between a NASA-led and -run human spaceflight program and national security, how does this loss of space industrial base harm national security? Whoever would wish to address that. Yes, ma'am.

Dr. ZUBER. Well, I would say surveillance and reconnaissance are two of the prime things that are associated with national security, and the same skills that are required to do that on the military side are part of the human space program. Students are never going to be inspired by things that go on on the dark side that they will never hear about but they are certainly very inspired to develop the technical and scientific skills that are necessary in the civil space program.

Mr. ARMSTRONG. When security is an issue, it is generally because there is perceived threat of some sort, and those threats are often directed toward weakness, and whenever any country has the high ground, as Captain Cernan said, has the technology clearly in hand, is on top of all the various disciplines and there are no perceived witnesses, it acts as a prophylactic, a discouragement of possibly initiating actions that are in the security range.

Mr. BROOKS. Mr. Chairman, I see I have run over time, but may I have 30 more seconds for a concluding remark?

Chairman HALL. Without objection, the gentleman is granted 30 more seconds.

Mr. BROOKS. I grew up in Huntsville, Alabama, and with great pride would feel the Earth shake and hear the boom and roar of the Saturn V as it was tested, the very same Saturn Vs that sent you gentlemen to the Moon, and I remember the day that you, Neil, touched down on the Moon and the pride that I had as a teenager in our country, and I pray that this committee and this Congress and the White House will give future generations that same feeling that I was blessed with with what you achieved.

Thank you, Mr. Chairman.

Chairman HALL. Well said, sir.

I have been told that another reason this is a national security item is that we may be defending in the next war partially out of space. I think that is to be remembered.

The Chair now recognizes Mr. Hultgren, the gentleman from Illinois.

Ms. HULTGREN. Thank you, Chairman.

I just want to say, Mr. Armstrong, Captain Cernan, you are exceptional Americans, and you have, whether you know it or not, been a part of, I believe, making America exceptional, and I just want to thank you for that.

A lot of people try to remember their earliest memory. I am 45. My earliest memory is standing in a playpen looking at a black and white TV screen watching you land, and that is amazing, but I also feel, as Congressman Brooks said, the pride and the challenge of that of wow, look what we did. It wasn't what you did, what we did. I didn't understand that then, but it went on with the entire program, and so I just want to say thank you. We are so grateful. And I know you are humble men and I am so grateful for that as well, but I do want to thank you for all that you have done and the sacrifices that you have made, the risks that you have taken, but the impact that you have had on our Nation and our world. I just want to thank you for that.

I do want to ask a couple quick questions. I know time is short on this, but Dr. Griffin, I wondered if I could ask you just quickly, you talked briefly about the Chinese. I am concerned about where things are there. I know the Chinese Long March 5 rocket is in development. I wondered if you could compare that to anything in the American inventory of what we have. When it is built, is it really larger than anything that we have built, and why do you think the Chinese are building such a large rocket?

Dr. GRIFFIN. Well, the Long March is comparable in scale to today's Delta IV heavy or to the Ares crew vehicle, which we were going to build and which was canceled, so it is on the order of, and of course, until it flies regularly, we won't actually know. But it is on the order of 25 tons of payload to low Earth orbit, so it is not in the class of, say, the Saturn V or the new space launch system, but it is a very significant capability, and in fact, by launching and rendezvousing four of those in low Earth orbit, it would be possible for the Chinese to construct a manned lunar mission with no more than that rocket and no more than Apollo technology, and I have in fact in the past written up how that mission would work from an engineering perspective. So with the Long March 5, the Chinese

inherently possess the capability to return to the Moon should they wish to do so.

Mr. HULTGREN. And you are saying we don't have anything that would be comparable to that, obviously, other than what had been talked about?

Dr. GRIFFIN. Well, we have nice viewgraphs.

Mr. HULTGREN. Thank you.

One other question I would like to ask, Mr. Armstrong, Captain Cernan. For a human space exploration program that we can be proud of here in America, do you think a 130-metric-ton rocket is big enough or would a bigger rocket be more appropriate? I wondered if while answering the question if you would consider the situation that we are in, the financial situation that we are in.

Mr. ARMSTRONG. As I said in my written testimony, that is not really a new idea. Twenty-five years ago, roughly, the national space strategy included building of a rocket of 136K tons, so apparently the rocket design experts have sort of focused on that area as being a reasonable range for most of the deep-space expeditions that they have envisaged. It is certainly clear that you get economy of scale with rockets, so the bigger you build them, the less expensive the payload is. So if you have a need for a really big payload in space, you could certainly probably conjure a need for something bigger than 130 into low Earth orbit. My guess is that because aeronautical and aerospace engineers are always able to stretch airplanes and make them bigger, that they could also find ways to take that basic spacecraft and make it haul a bigger load to orbit by putting on more strap-ons or different upper stage or whatever. It is probably doable.

Captain CERNAN. I am going to leave the experts to answer the economy-of-scale problems in one thing or another because I am not sure I am that smart, but my personal feeling is, when it comes to going to Mars, we are going to have to extend ourselves with some kind of propulsion system beyond something the size of the SLS. The SLS can get the hardware up there, and this is me talking. I am unwilling to accept a nine-month trip to Mars and to come back when the planets are aligned a year and a half later if that is the case and nine months to come home, and I am also unwilling to accept going all the way to Mars and not landing. So I believe somewhere along the line that chemical propulsion—going to the Moon is about the useful extent, I believe. Now, Mike may disagree with me about the use of chemical propulsion. We are going to have to develop a nuclear proton, some kind of other system that gets us to Mars in 60 to 90 days that allows us to stay as short or long a time as we want to stay and come home when we want to come home. I think that is the real key and the real secret to going to Mars. I think the SLS, that size of booster is probably necessary, I would guess, to get the equipment and hardware up there and get it on its way, but we can't use the planets and the gravity to coast like we did to the Moon. We coasted to the Moon. We can't do that going to Mars. We have to find something better.

Dr. GRIFFIN. Just to add on, Captain Cernan is quite right. It is possible to go to Mars with chemical propulsion but we really need to revitalize our nuclear thermal propulsion programs.

Gene, when you flew to the Moon, we had a nuclear upper stage that had been tested, was being tested, and the next thing it needed was a flight test, and it was canceled. So that alone would have made the difference. I am sorry to intrude but——

Mr. HULTGREN. No, it is good. I appreciate that.

Well, my time is up, but again, I just want to thank you for all that you have done, and this is personal for me. I have got four kids, 17 to seven. I love all my kids. My seven-year-old, Cole, wants to be a scientist, and I think he would love to be an astronaut. I would like him to be able to do that from America and not have to go to another country to be an astronaut, so this is so important, this is personal, and I thank you for all that you have done and you inspire us forward into the challenges that we have got to make sure that we remain exceptional as a Nation, so God bless you. Thank you so much.

Captain CERNAN. Can I get personal for 20 more seconds? Neil and I were the tip of the arrow. It is these folks, you folks, and you are here because you want to be. You are inspired because of space and aviation. Thousands and thousands of people out there were the strength behind the build. Tell your kids and every other kid you ever see, tell them the guys who went to the Moon said always shoot for the Moon because even if you miss, you are going to land somewhere among the stars. That is all they need. That is all they need to foster their dreams.

Mr. HULTGREN. Thank you.

Chairman HALL. I thank you. The gentleman's time has expired.

The Chair recognizes Mr. Cravaack, the gentleman from Minnesota, for five minutes.

Mr. CRAVAACK. Thank you, Mr. Chair.

You know, it is rare that you have the opportunity to meet a hero when you are a kid, and here I am in the presence of two of them, so thank you very much for everything that you have done.

All these years, Mr. Armstrong, and watching that film, my heart was racing. I knew the end of the story but at the same time, you know, my heart was racing the whole time because I knew what you had to do to get the LEM on the ground. So I appreciate having that opportunity to share that with you.

Captain Cernan and Dr. Armstrong, you know, you hit the nail on the head, at least for me, when you were talking, just momentarily about inspiring the youth, the next generation, because you were the guys who inspired me because at least when I grew up there, it was a small town in Madeira, Ohio, where I flew your mission a million times in a refrigerator box with a chair on its back. It eventually led me to becoming a Navy pilot, so I know we both share the wings of gold there. So you inspired me to become a Navy pilot, so thank you.

You know, space does inspire. It is amazing to me, probably this phone has more computing power than the LEM did, and here we are today. That is truly inspiring to know that this phone controls more computing power than what it took for the vehicle to land on the Moon. And I know that you are involved in a couple programs. We were talking very briefly, Captain Cernan, down in Pensacola about what you guys are doing down there. Could you expound upon that a little bit, how you are inspiring the next generation?

Captain CERNAN. Well, very quickly, we have had a program in place for about 20 years. It is a $40 million private investment program down in Pensacola at the Naval Air Station, not to make naval aviators out of everybody, although we might make a few, but to inspire young kids to dream, use aviation as the hook, get their attention, make learning fun. You can teach a kid anything. And we have a program down there called the National Flight Academy, and you walk in the front doors and you are on a USS *Reagan* or *Truman* or whatever carrier you want to be. You are immersed in an aircraft carrier for a week, seven or eight days of your time, and we hope when those kids come out of there they now believe that they can become and do anything they want to do, that they can make their dreams come true if they have some confidence and faith in themselves and they are given the opportunity by people like you and me. And this program is tied up with major universities—Georgia Tech, Embry Riddle, Texas A&M, and soon Purdue University. Neil and I have a personal attraction to Purdue, by the way. And that is the point. You have to start when they are eight and 10 and 12 and 15 years old to get their attention. That is what got your attention in that soapbox when you flew Neil's landing. I know this was a familiar scene. No doubt you have done it before.

But we have to start now. We have to give these kids something, and aviation and space is the something. The aviation will always be there. There will always be new airplanes. There will always be the Blue Angels. There will always be exciting things. But all of a sudden, some of these kids—and I know, when you talk to them, there is an emptiness and they don't know what they are going to go, and Neil said it a minute ago, do we have any use for the Neil Armstrongs in the space program today? Do we? No, I think we can create—send a lot of scientists and astronomers, and with all due respect, send some of your colleagues over to the Soviet Union, put them in a spacesuit, send them up to space, let them do their all-important research, but until we have the capability to get ourselves up there, we don't need the Neil Armstrongs of the world anymore. How important is Neil Armstrong to this country?

Mr. CRAVAACK. Well, I think we will always need Captain Cernans and Neil Armstrongs to be that model that everybody will try to become someday.

So I appreciate those comments, and Dr. Griffin, I have to echo what Steve Palazzo said. You know, I would much rather be a pilot on the ground wishing I was flying than being flying and wishing I was on the ground. So, you know, it is very important that we do a lot of these test models on the ground and I highly support that, so I can only echo that.

I am going a little bit over time here but I truly believe that there is a kid in a refrigerator box somewhere that is dreaming of deep space, and that is who we need to get to, and those are the engineers to build that program, to build that deep-space vehicle as well. So thank you very much and I appreciate all you have done for this great country of ours, and I yield back, sir.

Chairman HALL. The gentleman yields back. He used exactly five minutes, the only one today. Thank you.

The Chair recognizes, Mr. Benishek, the gentleman from Michigan, for five minutes—five minutes.

Mr. BENISHEK. Thank you, Mr. Chairman.

I just want to say what a pleasure it is for me to be here and listen to your testimony. It has been an inspiration to me. I remember where I was that day as well.

I am kind of curious about the nuclear propulsion thing that you mentioned there before, Dr. Griffin. Do we have that kind of research ongoing at this time?

Dr. GRIFFIN. No.

Mr. BENISHEK. All right.

Dr. GRIFFIN. I can say "no" in more ways if you like, but no.

Mr. BENISHEK. Well, I mean, I am concerned about our budget and unnecessary expense but I do see the educational problems of not doing this and maintaining the top edge of technology for peaceful methods and for defensive reasons as well.

Dr. GRIFFIN. This is to the point of my comment in my oral statement when I said do we want to have a real space program or not. When you have grand goals that are very difficult to reach, it unifies and mandates all of these separate pieces—crew vehicles, life support, radiation tolerance, nuclear propulsion, atmospheric entry technologies at high speed, greater producibility and manufacturability, higher reliability, higher standards of manufacturing—all of these and many, many more things—the need for scientific investigation, all of these are pulled together by the pursuit of a goal which is out of your reach, and that is to me what a real space program does.

Mr. BENISHEK. Does anyone else have a comment they would like to make? Captain Cernan?

Captain CERNAN. Are you Czech?

Mr. BENISHEK. Yes, sir.

Captain CERNAN. Jak se mas.

Mr. BENISHEK. Thank you.

I will yield back the remainder of my time.

Chairman HALL. The gentleman yields back, and the very patient Mr. Posey, I recognize you for five minutes.

Mr. POSEY. Thank you very much, Mr. Chairman, for recognizing me, and thank you for allowing me to participate in this important discussion.

The topic of this hearing, the future of human spaceflight, is critically important to my constituents, and of course, it is an honor to be here with our esteemed guests of heroes today.

My first real job was at Pad 17, as was our first panelist, and Dr. Zuber, I am glad you got to be at Pad 17, which is there no longer. As a young man, I got to work on the rocket ship that took you to the Moon, Mr. Armstrong, and brought you safely back, the third stage, Douglas subcontractor, and unfortunately, Mr. Cernan, I was laid off before it was your turn to fly, me and a couple of dozen thousand of our best friends.

But the future of spaceflight, human spaceflight, is critically important to the Space Coast that I represent. The economy, of course, all politics being local, is inextricably intertwined with our space program. The retirement of the shuttle program is a major

blow, obviously, to the district, mine and Representative Adams', who has the adjoining district, and we share the space centers.

I was encouraged by the promise of the commercial crew, and I think it is our greatest near-term hope for returning our astronauts to low Earth orbit and the International Space Station. Commercial crew, however, is both a needed commercial capacity and a NASA-led exploration capacity needed in order to retain our standing as the world's greatest spacefaring Nation and also to retain our dominance of the ultimate military high ground, which is space. Space to us is what Golan Heights is to Israel, and it is ironic, space and Israel are the two subjects I found here in Congress as I have been here that are absolutely nonpartisan, where are no party lines, even blurred. They are in step on both sides, thank goodness.

After a contentious summer including the first-ever Congressional subpoenas in NASA's history, NASA at long last revealed their initial plans for a space launch system that will carry the Orion capsule into future exploration missions. While many of us welcomed that announcement, the Administration has still not set out an adequate vision, and I intended, except you have made yourselves so very clear, all of you, in prior testimony, to get your positions on the necessity of us returning to the Moon, and I think—correct me if I am wrong—all of you have been very explicit in thinking that is a necessary step for this Nation. Am I correct? You are all shaking your heads yes. Thank you very much.

I have got more questions than I am going to have time to ask, but I am going to start with one that I am really curious about with Dr. Griffin. Current NASA plans seem to suggest the use of orbital fuel depots to enable exploration missions into deep space. What are your views? Is this a practical approach as a substitute for heavy launch vehicles, do you think?

Dr. GRIFFIN. Well, the short answer is no, but this time I will expand on that just a little bit. I think it certainly requires more study, but I think the onus is on those who want to advocate this approach to show that it makes sense because, first of all, it flies in the face of experience across all other transportation sectors that humans have yet built. The conventional wisdom is reflected in things like mile-long railroad trains. We don't send two or three cars. We have huge containerized shipping platforms. We try not to send small boats. We use supertankers, not again small boats. The air transport industry uses commuter jets for short-haul transportation, but if you are going coast to coast or intercontinentally, we are gravitating toward 787s and Airbus 380s. Either everyone else is wrong or space transportation is somehow different or depots just don't make sense. So I am in the camp that says so far I haven't seen the argument from an engineer's point of view that they make sense.

Earth orbit is short-haul transportation, so therefore we need smaller rockets appropriately sized to the crew vehicles we want to do. That is the 25-metric-ton-class Ares I, or an equivalent, because Ares I was canceled. If you want to go to the Moon or beyond, well, that is a long trip. That is a big trip. The depot advocates will say, well, 70 percent of what you need is fuel. Well, okay, but 30 percent is not. Thirty percent is really big hardware. And so that is

most easily accomplished by using a heavy lift launch vehicle. Well, once you have it, once you own a heavy lifter, just as once you own a supertanker or once you own a Boeing 787, well, then the economies of operation of those devices call upon you to use them as often as possible.

As Mr. Armstrong pointed out earlier, all transportation devices have economies of scale. Generally, the bigger that you can build them, the lower your overhead. So no, I am not yet convinced—strictly as an engineer, I am not convinced at all that the lowest-cost approach to deep-space exploration has fuel depots as its answer. I just don't see it. I wish it did because obviously that would make the problem much easier, so I wish it did. I just don't think it does. And I am primarily concerned that advocates of fuel depots are trying to answer the question of, what kind of human space exploration is most suited to commercial space rather than asking the question, how can commercial space best enable human exploration.

Mr. POSEY. Mr. Chairman, can I have one little follow-up?

Chairman HALL. Without objection, you can have a little.

Mr. POSEY. Just address some comments. I love commercial space, roots on the Thor before it was even the Delta where yours were, and we need commercial space, but I am a little bit chagrined when people say that commercial space is such a threat—or manned spaceflight, human spaceflight is such a threat to commercial. As I recall, there has never been a NASA mechanic or electrician that has assembled any of these rockets yet. I remember going back to your Apollo rockets and we had Boeing in the first stage, Lockheed in the second stage, Douglas in the third stage, IBM with instrumentation unit, Grumman was the payload. I mean, I think those are all commercial activities, and I think they spawn commercial growth of other activities. And so just a quick nod of the head agreement, disagreement.

Captain CERNAN. But it had insight and oversight, which commercial space today, to my knowledge, does not have.

Mr. POSEY. And should have.

Dr. GRIFFIN. Well, sir, if I might add, if the development is being done with public funds, then I think it is only correct to have oversight of government agencies into those developments. If a development is being carried out on private funds and then the product or the service is offered to the market for whatever the traffic will bear, then I would pat them on the back and say good on 'em. But if public funds are going to be involved in the development, then there has to be public oversight to ensure proper responsibility and accountability for those funds.

Chairman HALL. The gentleman's time has expired, and the questions are completed and I thank the witnesses for their very valuable testimony and tell you that the Members of the Committee may have additional questions. If they do, they will submit them to you in writing.

I want to ask Mrs. Kronmiller to express our thanks to Mike McCulley, too, for his long years of service in the United Space Alliance, USA.

We will ask you all to answer those questions in writing, and the record will remain open for two weeks for additional comments

from Members. And thank you, Ms. Johnson, for your input. I thank all of you, you're good witnesses, Dr. Zuber and these three gentlemen. This is the best hearing I have ever presided over. I thank all of you for your good work, and God bless you, every one of you.

We are adjourned.

[Whereupon, at 12:41 p.m., the Committee was adjourned.]

Appendix

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Mr. Neil A. Armstrong, Commander, Apollo 11

Question submitted by Chairman Ralph M. Hall

Q1. One underlying rationale of Apollo was the peaceful demonstration of American ideals and technological prowess in a highly visible yet exceptionally difficult undertaking. You experienced first-hand the world-wide adulation from successfully accomplishing such a monumental objective. It is often argued that spacefaring nations, especially those with human space flight capabilities, enjoy greater prestige and the advantages of "soft power" among the community of nations. From your experience can you offer examples of ways the United States benefitted in its interactions with other nations because of NASA successes in space?

A1. America's lunar landing achievement was widely perceived as a world achievement. An American friend of mine was the Consul General in Puerto Allegre, Brazil, during the flight of Apollo 11. He invited a few American friends in to watch the first lunar landing. About 200 people showed up (nearly all Brazilians) who, at the moment of landing were shouting "We did it, we did it!" President Nixon told the Apollo 11 crew that he had been able to get confirmed meetings with foreign leaders that he had previously been unable to obtain. Astronauts are warmly welcomed in almost any country. The American achievements in space seem to be universally respected. It is my hope and my belief that this respect can prove synergistic to other areas of respect and cooperation.

Questions submitted by Ranking Member Eddie Bernice Johnson

Q1. The recent loss of a Russian Progress vehicle and the ensuing grounding of the Soyuz rocket underline just how fragile our access to the International Space Station may be for at least five years. How concerned should Congress be about that situation, and how much priority should be given to the 2010 NASA Authorization Act's direction for NASA to provide a government back-up capability to service the ISS?

A1. For the first half century of American human spaceflight, we have always been in charge of our own destiny. When we had problems, we had the obligation to work our way out of them. It sometimes required additional time and money, but we were in charge. We are now in the position of not being able to control our own destiny. If access to low earth orbit and the ISS becomes unavailable for some reason, we have no satisfactory options.

In response to Chairman Gordon's question in conjunction with my testimony of last year, I stated that America's top human space flight priorities should be leadership, guaranteed access, and an exploration focus. Consistent with the second of those priorities, I believe Congress should do all in their power to guarantee safe, reliable access to low Earth orbit and the International Space Station.

Q2. As Members of Congress, we are frequently asked why we need to send humans to the Moon or Mars at a time when too many Americans are having trouble finding a job and making ends meet. What should we tell our constituents—what is it about human space flight and exploration that makes it worthy of the resource commitments we are asking the American people to make? What would be the impact of "pausing" until we got our fiscal house in order?

A2. Our nation's expansion into new territories or new areas of endeavor has always been met with substantial opposition. The Louisiana Purchase was criticized on financial, political, diplomatic, and even constitutional grounds. The acquisition won House approval by only two votes. The acquisition of Alaska from Russia also met fierce criticism on grounds of operating cost, geographic location, and inadequate population. It was known as Seward's Folly. America was militarily unprepared for both World Wars.

We should remember that up to the present time, we have spent no money in space. It has all been spent on Earth and predominately domestically.

While, in comtemporary terms, job creation is a prime objective, the real question asks whether this expenditure of taxpayer's money will result in a long-term benefit to the nation.

History suggests that it will. Opening new frontiers will engender new opportunities for our children and our children's children. Hopefully the resultant economic

opportunities will counteract the massive debt that they are inheriting from our current deficits.

Question submitted by Congressman Mo Brooks

Q1. In your experience, is a government-run human spaceflight program crucial to America's national security? In addition, noting the presence of China, Russia and others in space, is this Administration's approach to a commercially operated human spaceflight program a threat to America's national security?

A1. Leadership in human space flight ensures that the United States will maintain the technological edge and international stature to respond authoritatively and effectively to a wide variety of security threats. Other nations do, indeed, direct and operate their human space activities as a part of their military structure while we, generally, do not. I am unable to predict how that will affect our national security in the future.

The U.S. Military has, historically, acquired their weaponry and infrastructure needs from our commercial industry using procurement procedures that protect that nation's security and financial interests. Some of the probable participants in the commercially operated human spaceflight programs are very familiar with past practices including procurement, technical oversight, and auditing. Newcomers to this process advocate less such process and oversight in order to reduce cost and improve schedule. The national security consequences, as well as the technical and financial risks of these varying approaches, deserve the attention of the Administration and the Congress.

Responses by Captain Eugene A. Cernan USN (ret.), Commander, Apollo 17

Question submitted by Chairman Ralph M. Hall

Q1. In your testimony you touched on the loss of leadership and national prestige that occurred by the decision to retire the space shuttle without having committed to a credible alternative. Would you please elaborate on your concern?

A1. Mr. Chairman, with the unfortunate exile of our Space Shuttles to a future in museums around the country, we find our nation without the capability to put an American in space on American hardware for some undetermined time in the future. I personally believe under the present circumstances we could very well find ourselves in this position until the end of the decade. If I am correct, it makes the decision to retire the Shuttle, the only operational vehicle the Nation has readily available while still in the prime of its life—unconscionable. This opinion obviously shows my lack of confidence that commercial space will be a credible alternative for human access to low Earth orbit at any time in the near future. We are not only abdicating our commitment to our Nation's leadership in space, but additionally to our international partners to service their needs and cooperative efforts on the International Space Station. And, with this goes our national prestige and geopolitical influence that impacts respect from nations worldwide. Not to be overlooked with the retirement of the Space Shuttles, we have lost a major element of our national security as well as the capability to respond to ISS contingencies that can only be handled by the Shuttle's human and cargo payload capability. Nowhere in the near term is there anything we can rely upon to replace them.

Questions submitted by Ranking Member Eddie Bernice Johnson

Q1. The recent loss of a Russian Progress vehicle and the ensuing grounding of the Soyuz rocket underline just how fragile our access to the International Space Station may be for at least five years. How concerned should Congress be about that situation, and how much priority should be given to the 2010 NASA Authorization Act's direction for NASA to provide a government back-up capability to service the ISS?

Q2. As Members of Congress, we are frequently asked why we need to send humans to the Moon or Mars at a time when too many Americans are having trouble finding a job and making ends meet. What should we tell our constituents—what is it about human space flight and exploration that makes it worthy of the resource commitments we are asking the American people to make? What would be the impact of "pausing" until we got our fiscal house in order?

A1–2. Madame Chairman, without the Space Shuttle, now at the high point of its productive life, available to service the requirements of the International Space Station with both crew and cargo payload capability no other existing launch vehicle can approach today, we are abandoning control of our own destiny. We are exposing ourselves to a potential catastrophic failure onboard the ISS that might very well occur at some time within its extended lifetime, perhaps only preventable by Shuttle access to low Earth orbit. Should there be additional problems in the Soyuz launch vehicle, and based upon history, we certainly can expect, or should there be solvable problems aboard the International Space Station, we predictably know will occur, without government back-up capability we put the Station and crew at undue risk. It makes absolutely no sense in my mind to retire the entire Shuttle fleet, the only operational vehicle America has available for perhaps the balance of the decade without a reliable, proven capability as a back-up.

With the termination of the Constellation and retirement of the Space Shuttle, we have today as many as 40,000 aerospace industry jobs presently at stake. Within this number are highly qualified and inspired engineers, technicians, and other highly motivated and quality individuals, most of whom are now forced to seek employment elsewhere—difficult at best while we find our Nation's unemployment rate at or above nine percent. Every penny America has spent in space over the past half century has been spent here on Earth resulting in jobs at all levels, with an evolution of technology resulting in new industries leading to new businesses which in turn employ new workers.

Our investment in space has always been an investment in the future of this nation, not only in technology which leads to a better life here on Earth but an investment in the future of our youth as well. Space has created a wealth of new opportunities, development of new resources, created jobs and, perhaps most important, has inspired our young people. The dreamers of today are the doers of tomorrow, and

without dreamers and without doers, I believe our potential growth as a nation is severely limited. It's important to remember what we do not do today, will be done by others tomorrow—as evidenced by the Chinese long-term commitment in space today.

Question submitted by Congressman Mo Brooks

Q1. In your experience, is a government-run human spaceflight program crucial to America's national security? In addition, noting the presence of China, Russia and others in space, is this Administration's approach to a commercially operated human spaceflight program a threat to America's national security?

A1. Congressman Brooks, I believe it's absolutely essential to have government oversight in a government-industry partnership committed to human spaceflight. A half-century of experience has given us the insight to know what it takes in order to accept the challenge of human spaceflight. We have paid dearly for our mistakes so as to achieve the success history now records. As a testimony to the importance of the courage, dedication, and commitment of all those who made it all possible, it's important to remember "all who went to the Moon came home."

I sincerely do believe such oversight is extremely crucial to America's national security. Five decades of America's leadership in space is the result of such a relationship with our aerospace industry. The exploration of space itself is too risky, too important, with too many unknowns where Americans finds themselves vulnerable to a host of unknown problems to blindly turn it over to a commercially operated human spaceflight program with little or no track record. I believe this Administration has turned its back on its responsibility to the Nation and is expressing an unacceptable level of ignorance and disregard by not acknowledging the active presence of both China and Russia in their plans for access to near Earth orbit as well as future dominance in deep space exploration.

Responses by Dr. Maria Zuber, E.A. Griswold Professor of Geophysics and Head of the Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology

Questions submitted by Chairman Ralph M. Hall

Q1. How would the availability of a heavy lift launch capability support or augment space science missions?

A1. NASA's science missions do not require the significant launch load capability associated with a heavy lift launcher such as the proposed Space Launch System, but nonetheless the development of a heavy lift capability will be beneficial for science missions. First, the heavy lift development is essential for the human program that represents a significant fraction of the NASA technology investment. A strong technological base is critical for the NASA science missions to thrive, both in terms of a critical mass of workers highly trained in space technology, and for the development and testing of space-qualified parts and components. The implementation of human space exploration using the heavy lift capability also has significant potential to advance NASA science missions. When humans travel to destinations beyond Earth to explore, they will be able to deliver and deploy science payloads in places that robots cannot currently access. Deep drilling beneath planetary surfaces is one example of a scientific endeavor that would be enabled by the heavy lift capability.

Q2. What is the role of human space exploration in inspiring your students? What aspects of exploration interest them the most?

A2. A human presence in space is certainly one of the most inspirational endeavors, particularly for young people. When children dream, the scope of their imagination knows no limits. The word "impossible" is not in their vocabulary. They are attracted to the greatest challenges. At present, students are most attracted to the challenge of sending humans to Mars. While this goal will not be achievable any time soon due to economic challenges, bright students will continue to be attracted to space exploration as long as there is positive progress towards this goal. The development of a heavy lift capability is an important first step in providing a new sense of purpose to the human space program.

Questions submitted by Ranking Member Eddie Bernice Johnson

Q1. In space exploration, how valid is the old adage, "It's about the journey, not the destination?" If so, how can we sustain interest and support for a building block-type exploration program?

A1. If the adage is interpreted broadly, there is considerable merit to it, far less so for a literal interpretation. The actual cruise to a destination, aside from launch, approach, and other critical maneuvers, is unlikely to sustain the highest level of public interest. But the development of the technology required to undertake a journey of exploration, including robotic reconnaissance, stands a much greater chance of engaging the public. The emphasis on the importance of high-tech jobs with extraordinary skills required to achieve challenging plans needs to be kept in the forefront of public discussion. Inspirational leadership is crucial for underscoring the importance of the mission.

Q2. What are the potential benefits of the SLS and MPCV architecture for enhancing the capabilities of NASA's science program, and vice versa?

A2. The Space Launch System and Multipurpose Crew Vehicle collectively constitute the technological space infrastructure that will form the basis for the next phase of NASA's human exploration of space. When humans achieve the flexibility to travel to destinations beyond Earth, astronauts will be able to carry science experiments to sample the surfaces of solar system bodies as well as to make observations of interplanetary space. Particular benefit will derive from activities that do not fall within the current capability of robotic missions. Deep drilling beneath planetary or asteroidal surfaces is one example. Another is deployment of complex structures such as solar cells or antennae in deep space; such deployments have been demonstrated in low-Earth orbit during construction of the International Space Station.

Q3. Based on your experience in leading the GRAIL mission, could you comment on any aspects of NASA mission projects that may lend themselves to improvements

or efficiencies without compromising safety and can be incorporated in human exploration projects?

A3. Following best practices and engaging independent scrutiny are demonstrated ways of assuring a standard of engineering discipline that allows very complex systems, like spacecraft, to operate successfully. But over the course of GRAIL's development, I was shocked at how many things were done because they were always done that way rather than for any good reason that it contributed to increasing safety or lowering risk. I think it is very important to periodically review practices to assure that steps taken are actually increasing safety. My experience is that projects are being absolutely crushed by both oversight and paperwork that is taking time and resources away from studying the system to try to uncover potential problems. Whenever someone in the management chain gets nervous, more reviews get added; none ever seem to go away because they aren't adding sufficient value. Tabletop reviews populated overwhelmingly by technical experts who understand the system in question were exceedingly helpful to GRAIL. An important thing to remember in both the robotic and human space program is that more oversight does not necessarily make a mission safer. Ascertaining whether various forms of oversight are really reducing risk should be an integral part of project management.

Q4. How can NASA, in practice, stimulate and inspire our students? Is it through advanced technology projects related to future human exploration of Mars, the scientific research to support future human exploration, or through simulation projects and prize competitions? Are we talking about large dollar amounts for these efforts? How can we best channel and sustain the unbridled enthusiasm and intellectual curiosity of our students?

A4. The students at all levels with whom I interact are most interested in human exploration of Mars, but they are also interested in other destinations that challenge and excite them. The factor that seems to be most important to them is that the United States maintains a commitment to support an active and forward-looking space program. Realistically, such a program needs to have both human exploration and science components. While there are many students interested in the scientific part of the program, diminished support for human spaceflight is interpreted as a retreat in leadership in space exploration.

Projects and prize competitions are useful in engaging students; indeed, such activities are often influential (as are internships and other summer jobs) in exposing students to the exciting challenges in science and engineering. But students will also be asking where the jobs are when they graduate. Experience shows that only a small fraction of students who were motivated to study science, mathematics and engineering will end up working for the space program. But they do have an expectation that there will be challenging jobs somewhere in the country that will allow them to put their technical and scientific skills to work. The mission of NASA needs to be matched to its resources. NASA should not have political mandates to achieve goals that are inconsistent with its ability to implement.

Responses by Dr. Michael D. Griffin, Eminent Scholar and Professor, Mechanical and Aerospace Engineering, University of Alabama in Huntsville

Questions submitted by Chairman Ralph M. Hall

Q1. In your testimony you have a budget table that illustrates that between 2009 and 2016 some $50 billion has been removed from the Administration's human exploration budget requests and projections. Our hearing charter and your testimony both point out that the Administration has failed to heed its own Augustine Commission recommendations regarding the minimum level of funding necessary to have a human space exploration program worthy of a great nation. If the present budget is insufficient, what budget is needed?

A1. At a time when the NASA budget was about $19 billion annually, the Augustine Committee noted that an increase of approximately $3 billion/year was needed to fund a robust human exploration program while maintaining the International Space Station and our Science programs. This would have taken the agency to a level of approximately $22 billion in annual funding. If provided with this budget along with consistent, purposeful direction and stable, competent management, our Nation could accomplish a return to the Moon and the initial establishment of a lunar base by the early 2020s, even despite all the damage which has been done over the last nearly three years. To put this figure in perspective, I will note that the FY 93 NASA budget, the last under President George H. W. Bush, provided $14.323 billion. If this budget level had simply been maintained level in constant dollars, today's NASA budget would be approximately $21.6 billion, assuming the 2.3% annual inflation which is characteristic of OMB projections. Thus, the Augustine Committee was merely recommending a return to the budget levels in place at NASA prior to the gradual decline which was implemented during the Clinton Administration and which was halted, but not reversed, during the Bush Administration. It is clearly affordable, and if provided would allow real progress to be effected at NASA.

Q2. The Exploration Systems Architecture Study resulted in a human space exploration framework that not only included missions to the Moon but also established a lunar outpost. You recently presented a paper to the 62nd International Astronautical Congress which suggested commercial benefits of a lunar outpost. Would you please elaborate on some of the economic, scientific and strategic rationales for an outpost?

A2. My point with that paper, which is provided along with the present comments, was that even an elementary fiscal analysis will show that the cargo and crew logistics market for the International Space Station is insufficient, even under very generous assumptions, to generate a "closed" business case for commercial space transportation providers. Thus, something more is needed if the nation is to stimulate the development of commercial space capability in a serious manner.

The same analysis shows that "something more" could be a lunar base. The cargo resupply market for even an initial, four-person lunar base offers a sufficiently large market that at least two suppliers could be sustained by this government market alone, without incurring the enterprise risk of losing crew in an early accident. This last concern is of particular importance, because with the U.S. government allowing itself to rely upon commercial crew transportation to ISS, "enterprise risk" to the company is also enterprise risk to U.S. sustenance of ISS itself.

Volumes have been written about the potential utility of a U.S.-led, internationally developed lunar base. I am not sure that I can add significantly to the discussion, except possibly by posing the following thought experiment. Let us suppose that the U.S. does not redevelop the capability to go to the Moon and does not establish a permanent lunar base. At some point, China will develop this capability; all present signs point to a date not later than the mid-2020s for such, and quite likely sooner. I then ask: what does the global stature of the United States look like on the day after the Chinese land on the Moon, and we cannot do so? Do we think that other nations still regard the U.S. as the global leader in science and technology? Do we think that their view will affect their preference for executing deals and forming ventures with China vs. the U.S.? Do we think these preferences and choices will affect U.S. economic and national security interests in the world at large? I submit that the answers to these questions are obvious and unfavorable. When we look at the cost to the United States of not establishing a lunar base, the choices for our future in space are clear.

Questions submitted by Ranking Member Eddie Bernice Johnson

Q1. Now that the Administration has finally given NASA the go-ahead to proceed with the SLS and MPCV, how do we ensure that they avoid the fate of the Constellation program? What does Congress need to look for to determine whether or not the initiatives are going off the tracks once they are underway?

A1. It must be understood that the present Administration does not want to execute the SLS program, despite their signature on the 2010 NASA Authorization Act. Thus, it behooves the Congress to pay close attention to the program to verify that work being done under the auspices of the SLS program does in fact pertain to SLS development, and that it is central to such development rather than "on the margin." There is real danger that the Administration will manage the program in such a manner that because of bureaucratic bloat and lack of focus, it becomes a legitimate target for cancellation.

Q2. What is needed to help the program maintain momentum and maximize the program's inspirational value within the context of an incremental approach to human exploration?

A2. It is not widely understood that NASA has received as much money, in "real" or inflation-adjusted dollars, over the last 15 years as it received during its first 15 years, 1959–1973, a period which nicely encompasses the Apollo program and its essential precursors, Mercury and Gemini. The fact that we are justifiably proud of that seminal period in NASA and the nation's history, and the fact that the results of that time were purchased with no more money than we are spending today, indicates that the problem facing our space program is one of focus, purpose, and strategy rather than one of budgetary exigency.

It is true that in the time of Apollo, most of the funding necessary to accomplish the lunar landing was provided over a very short period, 1962–1966, with reductions thereafter as development was completed and operations were undertaken. Today, NASA's funding is relatively stable, so a major development "peak" in funding is not to be expected and, in fact, is not desirable. It is much more beneficial in the long run for NASA and its managers to be able to depend upon stable, consistent funding to accomplish a stable, consistent goal—the expansion of the human range of action in space. To this end, an incremental development approach to the re-establishment of our Nation's lunar mission capability is highly desirable—if only we can agree as a Nation that this is the fundamental near-term goal of our space program, and cease the current practice of "moving the goalposts" every time a new president takes office. When our Nation's youth understands that American leadership in space is, and will remain, a national priority, we will have all of the "inspiration" from the space program that is needed.

Q3. What, in your view, are some key lessons lerned from Constellation that the SLS and MPCV programs should heed as we begin to focus on ther implementation?

A3. The primary lesson that was being re-learned by NASA during Constellation development was the need to thin the ranks of the decision bureaucracy involved in managing the program. Not everyone who wants to be involved in SLS or MPCV should be allowed to do so. The expediency of decision making can be substantially improved if smaller management teams can be employed.

Q4. You conclude in your prepared statement that the present budget request for NASA is insufficient to accomplish any reasonable program of human exploration. If that is the case and constrained budgets are likely for the foreseeable future, what are Congress's options?

A4. In the absence of a clear sense of purpose for the Nation's human spaceflight program, the Science Mission Directorate at NASA has experienced substantial and excessive growth over the years. From an average of 17% during the Apollo years—hardly a period devoid of scientific accomplishment in space—NASA's science mission budget has grown to over 35% of the agency's portfolio. The development of human spaceflight was NASA's founding purpose, and should remain its central theme. In a time of constrained budgets, it is past time to reduce the fraction of the NASA budget that is devoted to robotic missions to a level that is consistent with the agency's fundamental purpose—the expansion of the human space frontier.

Q5. Your statement raises concern about the small amount of oversight exercised by NASA over companies participating in CCDEV–2, a preliminary commercial crew concept development effort. Does the just-announced new model for follow-on commercial crew development, where NASA uses normal government con-

tracts and not Space Act Agreements, address your concerns about oversight? If not, what more needs to be done?

A5. The now-planned use of FAR contracts rather than Space Act Agreements—if maintained—does somewhat reduce my concern about the lack of NASA insight and oversight on proposed new human spaceflight systems. However, the fundamental dichotomy still exists. These new developments are being touted as "commercial," but in fact are not commercial in any customarily accepted sense of the word. Front-end government funding is being provided to selected developers, who are pursuing their own designs to their own standards and who are objecting to the level of oversight and control that is normally expected to carry out development of new systems with public monies. While it is certainly true that private funds are also being invested to carry out these developments, the appropriate management approach to governing these "private-public partnerships" has yet to be demonstrated. I believe there to be a legitimate concern that the U.S. Government will be left with the responsibility for anything of a fiscal or technical nature which goes wrong, without having the necessary level of control to balance that responsibility.

Questions submitted by Congressman Mo Brooks

Q1. Under what circumstances is a commercial human spaceflight program viable and more cost-effective than a government-run human spaceflight program? If so, how long do you think it will take for the commercial industry to become a vibrant and reliable substitute for human access to low Earth orbit, and will this approach lengthen the amount of time that America is reliant on the Russians and others?

A1. A commercial offering of almost any product or service that can be provided "commercially"—meaning without government involvement save as a purchaser—should in my experience always be more cost-effective than its government-furnished equivalent. But that is not the point in question in today's debate over space policy. We do not use government because it is "efficient" according to any customary sense of that word. We use government to provide goods and services which the commercial sector is unable or unwilling to provide, or when such goods and services are judged to be of a crucial and strategic nature, such that society's dependence on the private sector to furnish them would be unwise. Many such examples exist; i.e., the U.S. Marines are government employees, not mercenaries, for reasons of this nature.

A similar situation exists with spaceflight today. While there is no doubt—none—that private sector engineers and managers are fully capable of developing human-rated spaceflight systems without government oversight, direction, and control, there is no apparent commercial market for such systems, and so the only "customer" is NASA; i.e., the U.S. Government. In such cases, the free market typically will decline to invest in such developments, quite logically leaving the development of systems intended for public use to be accomplished with public funds.

What we are seeing today is an arrangement proposed by the present Administration whereby front-end government funding is to be provided to selected developers who will, supposedly, furnish human-rated space systems for U.S. Government use, but over whose design, development, and operation the government—i.e., NASA—will have little effective control. NASA will not own the vehicles nor the intellectual property behind them when (or if) they are completed and, having paid to develop them, will then have to pay for their use. This is not a "commercial" business arrangement in any conventional sense, and in my view leaves a significant gap in the chain of public accountability which is normally expected of those who accept public funding for their enterprise.

Q2. With regards to funding for the Space Launch System, are the goals that Congress has set for NASA achievable, in the event that NASA refrains from "taxing" the program by diverting funds to unrelated and currently irrelevant programs?

A2. Yes.

Q3. With regards to the development of the Space Launch System, the word "simultaneous" in the FY 2011 CR bill language would be understood by most people as meaning that actual hardware work would occur on the upper stage. NASA gave me the impression that the upper stage hardware work would be delayed. Don't hardware and other components for any stage actually require awarding contracts two–three years ahead of time? I am concerned that NASA is not fol-

lowing Congressional intent and that delaying upper stage work will actually make it cost a lot more to the taxpayer when it is finally done.

A3. You are correct. NASA (actually the Administration) does not actually want to build the SLS. The behavior you cite is evidence of that fact. NASA is in fact not adhering to the intent of Congress in this matter.

Q4. Has NASA made any progress on developing technologies/systems for the next generation of launch vehicles/spacecraft, and if pressed, how soon could these be integrated into a system capable of sending U.S. astronauts to space?

A4. NASA does not need to, and has not, developed new technologies for launch vehicles at the present time. What is needed is to utilize technologies we already have to restore systems and capabilities we have lost. If we followed this path, we could restore NASA's capability to get people into space to support ISS operations within four years, and could return to the Moon within a decade.

Appendix 2

Additional Material for the Record

ADDITIONAL MATERIAL FOR THE RECORD

Letter to Mr. Neil Armstrong

SEDS

September 20, 2011

Neil A. Armstrong
[redacted]

Dear Mr. Armstrong,

The Students for the Exploration and Development of Space (SEDS) is the nation's largest entirely student-run organization dedicated to space. Over the past year, as many individuals have offered their opinions on the best way for the US government to foster the next stage of space exploration, a critical perspective has been missing from this conversation: that of America's current students. Since we, as students, will be asked to implement the space programs of tomorrow, we thought it would be useful to add the student perspective to the nation's current space policy conversation.

So last March, our organization put together a letter, signed by over 300 of America's brightest college students in space-related fields from over 35 universities, to express the opinion of college students on the future of U.S. human spaceflight.

We understand that you have been asked to speak to the House Science Committee of the U.S. Congress this week, and we would be honored if you would carry with you some of the messages that we 300 students put forth in our letter. The letter is attached for you to read. We would also of course welcome any comments that you might have. Thank you for your time and consideration.

Sincerely,

Rick Hanton

Rick Hanton
Chairman, Students for the Exploration and Development of Space, USA

Letter from College Students regarding the Future of Human Spaceflight

March 31, 2011

Dear President Obama and Members of Congress,

This year, as we celebrate both the fiftieth anniversary of human spaceflight and the accomplishments of the retiring Space Shuttle fleet, the exploration of space remains as critical as ever. Over the past year, many groups have offered their opinions on the best way for the US government to foster space exploration. However, one critical perspective has been missing from this conversation: that of the next generation. We, the signatories of this letter — 300 students from universities and colleges across the nation — are writing you today to ensure that our voice is heard in this ongoing discussion.

We are the ones who will be most affected by the decisions you make today. We are undergraduate and graduate students working hard to prepare ourselves for fulfilling careers as leaders and productive members of the civil, military, and commercial aerospace industries. We are the astronauts, engineers, scientists, and entrepreneurs of tomorrow.

We urge you to consider the following recommendations as you make the key decisions that will chart out the future of our nation's space program:

Everyone wins when NASA partners with the commercial spaceflight industry.
NASA always has been and, we hope, always will be the world's leader for human spaceflight. No other organization can boast of the accomplishments or the institutional legacy of NASA. However, NASA need not be the only way for people to get to space.

We believe that companies in the commercial spaceflight sector such as SpaceX, Virgin Galactic, and Blue Origin offer huge opportunities for us as students, and for our nation. Many of us are eagerly applying to work at companies in the commercial and entrepreneurial space sector. We do so partly because we are excited by their "Silicon Valley" spirit of innovation, their inspiring founders—Elon Musk of Paypal and Tesla Motors, Sir Richard Branson of the Virgin Group, Jeff Bezos of Amazon—and their fast-paced work environments. But we are also interested in working at these companies because we are greatly encouraged by the prospect of a future where these companies work alongside NASA.

We strongly believe that NASA and the nation both benefit greatly from investing in commercial spaceflight programs that will allow astronauts to fly on commercial vehicles; and we urge you to fully fund and support those programs. They offer a win-win situation: we ensure that the nation has a way--or, better yet, several independent ways--to get its astronauts into space following the impending retirement of the Space Shuttle, while the commercial sector will benefit from the support of NASA to grow faster and to hire more of us future graduates.

Open the space frontier to all.
For fifty years, NASA's astronauts have been heroes to the nation. We share that respect and admiration for the hardworking men and women of NASA's astronaut corps. However, access to space must not be limited just to this small group of people. Nearly all of us grew up wanting to be astronauts, and NASA should play a role in ensuring that that dream is open to all of us.

NASA and the US government can help make this dream a reality by doing two things: re-invigorating NASA's role as a technology development engine focused on advanced concepts, and fostering American businesses focusing on safely taking humans to space. The technology that gets us to space today is essentially the same as what carried John Glenn to orbit decades ago; and, if given the appropriate direction, NASA has the talent to develop breakthrough new technologies that will dramatically increase the human presence in the solar system. At the same time, commercial space companies large and small are developing routine, safe, low cost vehicles that will allow many more of us to become astronauts, payload specialists, and passengers. We urge you to embrace the commercial spaceflight industry and help fulfill the dreams of so many Americans who want to fly to space, whether for pleasure, for business, or for service to their country.

Allow NASA to explore the solar system again by embracing commercial spaceflight.
The International Space Station (ISS) is an amazing and unprecedented laboratory. It represents the culmination of decades of hard work and billions upon billions of dollars. With ISS just beginning to fully deliver on its promise, it is critical that we keep the station in orbit and in service. At the same time, we as a nation are also called to turn our attention beyond ISS. We are united in believing that, by embracing commercial spaceflight and thereby reducing costs, NASA can refocus its exploration program to look beyond Earth's orbit.

Whatever the destinations--the Moon, Mars, and the asteroids each hold their own appeal--what is important is that NASA be directed to send humans to explore our solar system, and to do so not on brief sorties but as part of a sustained exploration effort that constantly

expands our knowledge and opens us up to new technologies and new opportunities. We are not a generation motivated by just flags and footprints; we desire exploration that is both inspirational and financially sustainable, and that will open up the solar system for exploration on a grander and more exciting scale than ever before.

This goal can be achieved by using new technologies achieved by NASA as well as new commercial vehicles being built by a wide range of American companies. Already, commercial firms are developing the capacity to deliver cargo and crew to ISS and to robotically explore destinations like the surface of the Moon. We urge you to direct NASA to use these commercial services wherever possible and to take advantage of the cost savings they offer to push ever further out into the solar system. NASA's mission isn't to be stuck circling in Low Earth Orbit; NASA should be exploring the frontier and developing new technologies.

Commercial companies will help grow tomorrow's workforce through inspiring STEM outreach and hands-on training.

Many people have spoken about the need to encourage more students to pursue careers in science, technology, engineering, and mathematics (STEM). As students, we believe that commercial companies—benefiting from the promotional resources and public attention that private firms command—will do a spectacular job of inspiring the next generation of STEM professionals. After all, what could be more inspirational than telling America's youth that they will have the opportunity to go to space themselves; not just a handful of the most talented and fortunate, but all of them who desire to do so? The prospect of working for these firms or going to space using their vehicles and services will inspire a new generation of engineers and scientists to take the most challenging classes in school and to develop new technologies and experiments that will make a positive difference in the world.

The low costs and high flight rates offered by commercial spaceflight providers also present a unique opportunity to allow students the chance to work on real projects that are flying to space. It is critical that students begin to acquire hands-on experience to complement our classroom studies, and commercial space flights allow low cost, low risk, and frequent opportunities for young scientists and engineers to develop real space hardware. Commercial spaceflight can play a key role in giving students valuable experience that will make us more productive members of the space exploration community or any other high tech field.

Conclusions

Thank you for your consideration of our thoughts on this important subject of human spaceflight. Here's a final story worth considering: as NASA inspired and amazed the world

by landing humans on the surface of the Moon in the late 1960s, the average age in NASA's Mission Control was only about twenty-eight. People not much older than we are now played an enormous role in one of the crowning achievements in the history of the world. We believe that if NASA is refocused on developing new technology and on operating in partnership with the emerging commercial spaceflight sector, the youthful energy and excitement that allowed the Apollo missions to inspire the world and to reach unprecedented success will be rekindled. These commercial firms are the places we as students are most eager to work; and that enthusiasm is spilling over to NASA as the space agency begins to partner with this new industry.

The decisions you make today will decide whether we as a nation truly progress forward with our space exploration endeavors, or whether we lose out on the promise of the moment. We thank you for allowing us to make our opinions heard.

Sincerely,

The following list of students from universities nationwide:

Aaron M. Valentine
Class of 2014: BS, Mechanical Engineering, Rensselaer Polytechnic Institute

Adam Yozwiak
Class of 2011: BS, Electrical and Computer Engineering, Cornell University

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ENABLING COMPLEMENTARY COMMERCIAL AND GOVERNMENT ENTERPRISES IN SPACE

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The human exploration and development of the space frontier for the benefit of society is a common theme in national and international space policy discussions. At the same time, it is increasingly recognized that private enterprises and individuals may have distinct and more immediate interests in space developments, deriving from the unique attributes of the space environment. The extent to which governments can and should encourage such private interests, and the means by which this might best be done while continuing to preserve and protect the larger public interest, is a topic at the forefront of space policy. In this paper, we consider various imperatives for the human development of space, public and private, and the relative strengths brought to the task by each. Two possible public policy initiatives designed to promote the creation of free markets and the private development of space infrastructure are explored – one centered on crew and cargo resupply to the International Space Station and the other on lunar base resupply.

I. INTRODUCTION

As has been discussed by numerous authors, the early development and exploitation of space systems and capabilities was primarily motivated by the superpower competition of the Cold War. Many such systems were of a directly military nature, such as intercontinental ballistic missiles, reconnaissance satellites and missile defense systems. The development of these systems was largely responsible for creating the industrial base which made other applications possible. Many derivative applications, including communications, weather observation, Earth resources analysis, and global navigation, offered benefits in both the civil and national security arenas. But even space systems having apparently altruistic purposes, such as astronomical observation, space physics, and planetary exploration, also played a strong role in Cold War competition; each new scientific achievement was touted as a victory for either the United States or the Soviet Union.

Nowhere was the competitive nature of the early space enterprise more clearly defined than in the development of human spaceflight. Human spaceflight, the sector offering the least-obvious immediate benefit to society, was nonetheless the most globally significant. From the straightforward development of the technological and industrial base that was required, to the less obvious but possibly more important matter of stature in the eyes of the world, the benefit to the United States from winning "the moon race" was incalculable. In retrospect, the Cold War was won in space, from ICBMs and strategic defense and "live via satellite" and Viking and Hubble and GPS to, most visibly, Apollo and Shuttle.

But as individual competitions are won or lost, circumstances change, and the grounds for competition change. Human competitiveness is certainly an enduring motivation, but as a sustainable underpinning for any given enterprise, it is less so. If an enterprise is to be sustainable in the long term, it must offer accrued benefits greater than the cost of attaining them. Private enterprises must furnish a positive fiscal return on investment. Public enterprises must provide an important benefit to society. Judgments in the latter case are considerably more difficult to make than in the former. Indeed, it may be observed that a considerable amount of political debate concerns the effort to determine a course of action when the "return on investment" occurs on time scales incompatible with normal investment criteria, is not easily expressed in monetary terms, or is considered to be so important to a society that it should not be left to the vagaries of the market. These observations bear directly upon the ability of governments to create and maintain a stable policy environment for space development.

To date, the development and application of space systems has been an overwhelmingly governmental activity. The notable counterexample has been the communications satellite industry, followed more recently and to a considerably lesser extent by the commercial satellite imagery industry. Both have benefitted from both favorable governmental policies and a substantial government market but, having overcome high early barriers to entry, now appear to be viable. Despite these examples, however, it remains true that most space system developments have been publicly funded and directed enterprises, or minor commercial adaptations of such. This is particularly so for the launch vehicles which provide access to space – the *sine qua non* of any future development of the space frontier.

But many today believe that private interests and enterprises have it within their capacity to develop and operate not only conventional communications and imaging satellites, but also large launch vehicles, human spaceflight systems, etc., and that government involvement in these areas, other than as a reliable customer, is no longer needed.

Two successful launches in June and December 2010 of the SpaceX *Falcon 9*, developed without government direction and with substantially less government financial support than has been typical in the past, lend credence to this view. Other successful privately initiated space enterprises are expected to follow and, if successful, portend good news for proponents of space development. Governments will want to encourage such activities. However, the most appropriate means of doing so is not yet clear; more questions have been posed than answers found.

Ultimately, the establishment of successful commercial space activities and entities is unlikely without the creation and promulgation of thoughtful public policy designed to promote them, as well as the growth of non-government market demand. To that point, it will be useful to review the features of both private and public enterprises, identifying the necessary aspects of any public policy designed to encourage and enhance the development of space.

II. PRIVATE ENTERPRISE

Sustainable private enterprises require, among other things, the ability to attract investment capital and to provide a competitive return on that investment. For any given expected return, those opportunities appearing to offer lower risk, shorter payback times, and lesser initial capital requirements are more attractive to investors than contrariwise. These factors are important to any discussion of private investment in space enterprises.

In recent decades, the least risky investments have been U.S. Treasury bills, offering approximately a 2.5% annual return. At a slightly higher risk, high-grade corporate bonds have yielded an annualized return of about 5.5% over the period from 1926-2010. With more risk, the equity markets have provided an annualized return of about 10% for this same period. Inflation from 1926-2010 has averaged about 3.2%, so the annualized real return for high-grade corporate bonds is about 2.3% and that for the stock market is likewise about 6.8%.

Riskier investments must offer substantially higher returns and other favorable terms if they are to be preferred over, say, a typical equity market index fund. Thus, venture capital investors typically seek returns of 40% or more with a three-to-four year payback time, with capital commitments of a few million, or a most a few tens of millions, of dollars.

Additional conditions must also exist for the development of a sustainable private market for any particular good or service. The product must be of a nature that it can be monetized. Many things which might be in the public interest are nonetheless extremely difficult to evaluate in financial terms. An obvious example is "national security". The cost of this product is easily measured, whereas its value is most elusive, being nothing less than the value of one's entire society.

Markets do not function effectively when costs and benefits cannot be directly linked in an arms-length transaction. When costs are concentrated and benefits are diffused, the result is "the tragedy of the commons". In the aerospace sector, this manifests itself when, for example, the easily identifiable fixed costs of launch facilities, laboratories, or the air traffic control system are balanced against the less directly observable benefits of owning such things.

Conversely, when costs are diffused but benefits are concentrated, the problem of "special interests" arises. Whether for milk producers or commercial space launch providers, subsidies and subsequent market distortions are a likely result.

Finally, private enterprise cannot exist without the sanction of the society in which it is embedded. Some clearly profitable activities are not permitted because they violate accepted societal mores or are judged to be broadly harmful; these impermissible

activities vary considerably from culture to culture and time to time, but the principle remains valid.

At the opposite extreme are those enterprises deemed too important to be hostages to the vagaries of the market. This definition too varies with place and time; Roman armies made extensive use of mercenary troops, whereas no great power does so today. Similarly, some societies choose not to leave the development and operation of extensive transportation, energy, or communications infrastructures in private hands, while others do.

Some enterprises, strategic or otherwise, do not by their nature offer the practical possibility of free-market competition. The electric power generation and distribution industry and the cable television industry offer examples at opposite ends of the scale of importance to a society. They have in common that they cannot easily be obtained through alternative sources in a free-market competition. When these services are provided by means of private ventures, such ventures are generally very carefully regulated.

The conditions for the existence of a sustainable private enterprise are thus seen to be rather restrictive. When a proposed venture is of a permissible nature, when it can be monetized, when straightforward transactions for its products are possible between provider and consumer, when the venture can provide a return on investment commensurate with its perceived risk, when that investment is of manageable size, and when the return can be expected within a few years, it is likely that competitive private enterprises will provide the most efficient satisfaction of a consumer need. When these conditions are not met, then the venture will be addressed by other means, if at all.

III. PUBLIC ENTERPRISES

At the opposite end of the spectrum are publicly-directed enterprises. Because public activities inherently involve the confiscation of individual wealth by the larger society, in an amount and for purposes of which the "donor" may not approve, the question as to which societal activities should be pursued as public ventures goes to the heart of human culture, of how a society chooses to organize itself. This question is far broader than, but bears directly upon, the present topic of space development.

There are several broad categories of activity in which societies have historically and with some consistency chosen to invest. When clearly strategic purposes are involved, such as expanding the society's sphere of influence by developing a frontier, or pursuing international partnerships and alliances, publicly funded and directed activities are the near-universal rule. Private enterprise may be involved, as with foreign military sales and the like, but will be in support of and subsidiary to public policy.

When the public interest requires the production of non-market goods and services, government investment will be employed to bring about a result that the market cannot. Such products and services are typically of a special-purpose nature, available from a limited number of suppliers, and of interest to only a limited number of customers.

Even where a potential commercial market may exist and can be foreseen, and even when the ultimate value of the product is not in dispute, government investment may be required if the barriers to entry are very high or the payback time is excessive relative to competing private investment opportunities. In the 19th Century, the American development of the Transcontinental Railroad, estimated in 1863 to cost about $10 billion in present dollars, posed just such a case[1]. In a more recent example, the world market for global navigation satellite services (GNSS), including core hardware and location-based services, is estimated to be $275 billion[2] presently, and growing at 11% per annum. Such a market is sufficient on its face to justify commercial deployment of a satellite navigation constellation, if one did not exist. However, it was not sufficient to attract the tens of billions of dollars of development cost required over a two-decade span to bring the U.S. Global Positioning System (GPS) to fruition.

Satellite navigation is an example of a more general case. Especially in the decades following World War II, it has been understood that acquisition of knowledge through basic research, and the advancement of technology before profitable ventures are readily foreseeable, are worthy goals that can sometimes be attained by means of public investments when market forces cannot do so.

Finally, when a venture is judged to be very risky or the consequences of failure are very costly, a public venture may be undertaken in order to spread the risk and its consequences over the largest possible base.

None of these concerns by themselves specifically precludes commercial activity, but they do pose impediments to such activity. All of them are relevant to the development of space applications in general, and of human spaceflight in particular.

It is specifically noted that "efficiency" is not offered here as a likely rationale for a public enterprise. No rational decision maker expects a government effort to be "efficient", as the term is customarily employed. The claim that private ventures are to be preferred over public ventures because industry is more efficient than government, while generally true, is irrelevant. Any private concern which cannot function more efficiently than a government entity which produces the same things would by definition require a subsidy merely to operate on par with the public venture.

Public ventures may be initiated and supported by a society for numerous reasons, as outlined above, but "efficiency" will not often be one of them.

IV. PRIVATE ENTERPRISE AND SPACEFLIGHT

The human development of space remains, after more than fifty years, a discretionary activity of a half-dozen advanced societies (United States, Russia, China, Europe, Japan, and Canada), only two of which possess the present capability merely to get to space on their own. Moreover, human spaceflight at present consists of a few crew-rotation flights annually to a single space station two hundred miles above the Earth, the development of which has consumed the human spaceflight budgets of fourteen partner nations for the last fifteen years. This seems unimpressive when viewed against the plans and dreams of space advocates a half-century ago.

Clearly, no compelling case has been made that rational private investors should undertake major space development efforts. One can argue that regulatory uncertainty and other government policies, such as Shuttle payload pricing prior to the loss of *Challenger*, contributed to this, but inherent structural factors exist as well. Let us consider a simple commercial space investment in order to understand the impediments to the market-driven development of space flight in general and human space flight in particular.

The lowest risk commercial space investments so far have been in the communications satellite market. As an example, we consider the case of a high-end communications satellite with fifty-six transponders, delivered on-orbit for a half-billion dollar net-present-value (NPV) initial investment. We assume a three-year development, with returns in equal real-dollar increments beginning in Year 4 and continuing for fifteen years until the depletion of stationkeeping fuel, at which point the asset has no further value.

As this is written, the market for a 36 MHz-equivalent geostationary transponder is in the range of $1-2 million/year, depending upon terms and conditions. If we assume an average of $1.5 million per year, then the satellite in our example will generate $84 million of annual revenue. Inflating the out-year revenues at the June 2011 CPI rate of 3.6% yields an internal rate of return (IRR) for this project of 13.0%, or a 9.4% real return. This is to be compared to the 6.8% average real return from the equity market. The 2.6% difference between the two is the "risk premium" the market requires for investment in a communications satellite venture – the least risky of space investments.

If the investor uses a discount rate of 10% to assess the net present value of his returns (i.e., the market return he chose to forego in favor of this venture), payback of the initial investment occurs at the end of Year 13, after ten years of operation. Any profit on the investment in excess of that which could have been obtained from the equity market occurs in Years 14-18.

This example illustrates the key features of private space enterprises: large initial investments, lengthy payback times, and significant risk premiums. And as noted, communications satellites have proven to be the most successful of the commercial space ventures proposed to date.

Let us now consider the nascent commercial human space transportation industry. As an example, consider an enterprise which is formed to develop a launch system to deliver approximately 9000 kg (20,000 lb) to the International Space Station orbit at 400 km altitude and 51.6° inclination. The anchor market for the company is the U.S. logistics support requirement for ISS; i.e., 15,000 kg/year for cargo, and two crew rotation flights per year offering four seats per flight.

While it is difficult to assess a business that does not yet exist, we can examine the viability of a proposed enterprise subject to certain bounding assumptions. To that end, we assume here that:

1) The company must develop a launch vehicle, a launch facility, an ISS-compatible cargo delivery vehicle, and a crew vehicle.

2) The crew vehicle will be a human-rated variant of the cargo vehicle, with additional investments for the required crew systems; thus, investments for the ISS cargo delivery vehicle apply to the crew vehicle as well.

3) Best commercial practices are employed in an aggressive development program, with Year 1 net-present value (NPV) non-recurring costs for the major system elements as follows:

Launch Vehicle	–	$350 M
Launch Facility	–	50 M
ISS Cargo Delivery Vehicle	–	200 M
Crew System Upgrades	–	100 M
Total Expenditures	–	$700 M

4) The cargo launch and delivery system will be developed over a four-year period, with revenues beginning in Year 5.

5) Crew transportation revenues begin in Year 6.

6) The ISS remains in operation through Year 20 of the enterprise; i.e., there is a sixteen-year market for commercial cargo service, and a fifteen-year market for crew transportation service.

7) The company captures half of the ISS market; i.e., 7500 kg/year of cargo and one crew rotation flight per year.

8) December 2008 NASA Commercial Resupply Service (CRS) ISS cargo contract pricing of $59K/kg is assumed when service begins in Year 5, and is inflated at the June 2011 3.6% CPI for out-year deliveries.

9) Crew transportation is priced at $125 M/seat in Year 6, double the average price of Russian Soyuz service in 2014-16[3], and inflated at 3.6% in subsequent years.

10) The company offers launch service in the non-ISS market also, with pricing at $150 M/launch beginning in Year 5, inflated at 3.6% per year thereafter.

11) Four non-ISS launches are carried out in Year 5, the first year of operations, increasing at the rate of two launches per year to twelve in Year 9 and remaining constant thereafter, yielding a steady-state launch rate for all customers of at least fourteen per year, depending upon how the ISS cargo flights are manifested. (For comparison, various versions of the Delta launch vehicle were launched twelve times in 1967, and thirteen times in 1998 with one failure. Atlas and Atlas-Agena launched thirty-three times in 1966, with three failures. In 1967 and 1978, fourteen Atlas vehicles were launched, and in 1995 twelve were launched.)

12) The company operates with a net profit margin of 10% across all lines of business (39% higher than 7.2% average for the aerospace and defense sector[4,5]).

13) No developmental failures resulting in additional expenditures or delays to the program schedule occur.

14) No operational failures resulting in the interruption service or additional expenditures occur in the course of the 179 flights which occur per the market capture assumptions above in Years 5-20.

15) No modifications or upgrades requiring significant additional investment are necessary in Years 5-20.

Subject to these assumptions, this enterprise would offer an IRR of 20.5%, well below the 25-30% that might be expected for a venture with this level of risk. At this IRR, the separate ISS cargo and crew businesses yield negative returns on the investment required to bring those capabilities to market. The combined ISS cargo/crew business still offers a negative return at the enterprise IRR. Internally, the ISS market is subsidized by the assumed non-ISS launch market.

At a discount rate of 10%, payback of the initial investment occurs late in Year 10, after six years of operations.

More aggressive assumptions yield only marginal improvement. For example, if the company captures the entire ISS cargo market beginning in Year 5 and wins half the crew market starting in Year 6, the IRR increases to 22.8%, with payback late in Year 9. Similarly, capturing half the cargo and all of the crew market yields an IRR of 22.7%, with payback again late in Year 9. The company has to capture the entire ISS logistics market through Year 20 to attain an IRR of 24.7%, with payback early in Year 9.

Obviously, a wide variety of assumptions could be used to model a prospective enterprise of this nature. To this point, it is useful to recall that "all models are wrong, but some are useful"[6]. The assumptions employed here were chosen to be challenging but not wholly unrealistic when considered individually. However, as a group they would appear to be quite

optimistic, yet even so this business is not an attractive investment by customary standards.

This analysis argues that existing market incentives are insufficient to bring about human space development by private enterprise even under very optimistic assumptions. The ISS logistics market is too small, no single competitor can expect to capture it all, the rate of return is low in relation to other investments having less risk, and in any case that market is temporary. Moreover, even with the generous assumptions employed here, the ISS business operates at a loss. The enterprise IRR improves if the human spaceflight market is ignored.

Finally, though not discussed here in any detail, the history of human spaceflight accidents strongly argues that the enterprise risk increases significantly if the crew transportation market is pursued.

V. PUBLIC ENTERPRISES AND SPACEFLIGHT

If human spaceflight has so far failed to attract the investment necessary for private development for the reasons discussed above, it is equally true that the long-term benefit to society that is necessary for a sustainable public enterprise has not been demonstrated. Logsdon[7] claims that this is because, after Apollo 11, "there was no compelling rationale to continue voyages of human exploration", that Apollo was "unique".

The question of what constitutes a "compelling rationale" for a public enterprise is crucial to space development. As early as 1969 the Agnew Commission[8] put forth a plan to continue human exploration of the Moon and move onward to Mars, utilizing and expanding upon the technology and systems created for Apollo. While undoubtedly compelling to the members of the committee, the plan was not accepted by President Nixon. But because the plan was not accepted does not mean it would not have been "compelling" to a different leader, or at a time when an unpopular war was not diverting American attention to other matters of possibly greater strategic significance. Indeed, if the definition of "compelling" is "that which would have caused President Nixon to make different decisions", many things of great value to American society were apparently not "compelling" between 1968 and 1974.

Thus, if Apollo was "unique", it is because a specific decision was made not to continue to utilize and evolve the Apollo-era systems for the purposes for which they had been built – human space exploration beyond Earth orbit. The present author has shown[9] that this could have been done within even the constrained fiscal resources allocated to NASA at the time. Thus, although regular and continued human exploration beyond low Earth orbit was not sustained, it was in fact sustainable. Apollo as an enterprise was therefore not inherently "unique". It was made so as the result of a conscious decision by an American president. The uniqueness of Apollo was a consequence, not a *prima facie* condition.

But – crucially – substantially stronger arguments are needed to initiate a major public enterprise than to sustain one. Once set aside, the nascent interplanetary exploration infrastructure of the Apollo era was as difficult to re-establish as private spaceflight has been to create. No U.S. president has chosen to reinvigorate the nation's human spaceflight program by providing the funding necessary to reach a sensible, attainable goal beyond low Earth orbit (LEO). Absent a crisis response akin to the U.S. reaction to the flight of Yuri Gagarin, this seems unlikely to change.

Logsdon[7] argues that this is so because, today, there is no societal question for which "going to an asteroid, or indeed anywhere else beyond Earth orbit" is the answer. But in fact there are numerous such questions, among them:

1) What is the nature and value of a human future in space?

2) What directions will human society take as a result? What social and cultural values will evolve and prevail, and how will we influence these developments if we are not there?

3) How is national security affected if we are not active on the human space frontier?

4) Can the nation remain open, vital, relevant, competitive and forward-looking in science, technology, culture, and commerce, if it is not engaged in developing the frontier of its time?

These questions will eventually be answered by means of human space exploration. But so far, the value of those answers has not been seen by U.S. policy makers to be worth the cost of obtaining them. As global technical capability continues to advance, other societies will be confronted with the same options, and may choose differently.

V. BLENDED VENTURES

If neither private nor public investment alone is adequate to bring about sustainable human space development, then advocates must turn to the

possibilities inherent in a blend of the two. This is a classic means of structuring an enterprise where the potential for both public good and private gain can be foreseen, provided the economic barriers to entry can be surmounted.

If government can provide appropriate incentives, the risk and return on private ventures can be improved to the point where rational investors can be attracted. When private enterprise can be engaged, greater execution efficiency is likely, resulting in a higher level of accomplishment, more quickly, for given expenditures. The political view of what constitutes a worthwhile "public good" is thereby also rendered more favorable. There is thus real value for the larger society in the development of a commercial space industry, even if the core market for such an industry continues for some decades to be the fulfillment of public goals.

The structuring of an enterprise so as to foster a viable industry where none exists, in a manner that is attractive to both voters and investors, requires very carefully crafted public policy. There are many ways in which the size and power of the government market can be used to help bring about new industrial capability. Historical approaches include prizes, direct subsidies, tax incentives, joint ventures, development of common-use public infrastructure, and the provision of guaranteed markets.

Prizes can be effective in drawing attention to a particular area, and in stimulating state-of-the-art competition, as for example with the Orteig Prize for the first trans-Atlantic flight and the Ansari X-Prize for the first human suborbital space flights. In both of the above cases the prizes were offered by private entities, but government could do so as well.

Prizes by themselves do not offer a useful tool for sustainable development, because a typical prize rewards only a single winner. A series of prizes can potentially accomplish what a single prize cannot; i.e., the progressive development of capability in response to a carefully structured system of rewards. In a graduated-prize system, multiple early winners must be accommodated if there is to be a reasonable expectation that an industrial base, rather than a single company, is to evolve.

Subsidies offer the most direct method of reducing the required private investment in an enterprise to a level that renders the financial return attractive to private co-investors. The use of subsidies is tempting when it is believed that the product being developed and offered is in the public interest, despite the lack of market viability.

However, the political risk that the promised public investment will continue for the required duration can be very high. If not all potential providers can be included in the subsidy, those who are not become political opponents, calling into question the criteria by which some providers are selected for investment and others are not. In a democracy, it is difficult in the extreme for public officials to "pick winners" in a manner that is sustainable for the long term. If it is difficult to rationalize selecting a "winner", when others claim that they, too, could be winners if subsidized, how much more difficult is it to sustain such subsidies if one of the putative "winners" actually fails?

Subsidized development programs can be difficult to manage in practice. A subsidy is essentially a government co-investment, and most investors do not closely manage the enterprise in which they have invested. However, if the government does not provide direction to accompany its investment, and the enterprise encounters difficulty, opponents will note the lack of oversight and control which is normally expected to accompany the expenditure of public funds. If the government does provide significant direction, and difficulty is encountered, private investors and corporate managers will ascribe the failure to the fact of that direction. And even if it is successful, an enterprise managed according to the rules customarily imposed upon government managers will likely sacrifice the very operating efficiencies that the use of a private enterprise was intended to achieve.

Finally, the ethical justification by which public funds are allocated to a private concern, without the compensating ownership of the end item and the intellectual property associated with it that is accorded to other investors (who, as a group, actually "own" the company), is questionable at best.

It is sometimes argued that government awards of negotiated or "prime" contracts to (typically) large, well-established industrial concerns are essentially subsidies by another name. While standard practice in the aerospace industry today, such contracts were not legal in the U.S., other than in wartime and in post-war extensions, until 1949[10]. Until that time, the so-called "arms-length" commercial contract was the standard in government procurement as well; i.e., other than a deposit of "earnest money", the customer does not pay in advance of delivery. Working capital is provided by the contractor. The customer pays for

the product when it has been delivered or, in the case of very large purchases, provides progress payments upon completion of agreed-upon work packages.

Negotiated contracts do carry the same burden of concern about "picking winners" as does the grant of an outright subsidy. However, these contractual instruments differ significantly from subsidies in terms of the open and exacting process by which winners are selected, the exhaustive oversight and specific direction provided by government officials during the development phase, and the public ownership of the resulting product and its associated intellectual property. While generally inefficient, this approach to the public acquisition of private sector goods and services is intended to be fair to all potential providers and to provide official accountability for the expenditure of public funds. By and large, it achieves those ends. However, because the provider is carrying out the product development at government behest and with public funds, this acquisition approach offers no public-private synergy, does little or nothing to spur private development of comparable capabilities, and in fact is usually detrimental to that goal.

Tax incentives are an alternate form of subsidy, with the key difference that, to qualify, the receiving entity must be sufficiently successful that it pays taxes. Thus, as with prizes, public officials are not "picking" winners, they are identifying and rewarding them. However, for investors in potential space enterprises the present value of even very substantial future "tax breaks" may well be insufficient to attract the necessary investment. Further, the required subsidy to achieve the "critical mass" necessary for the effective execution of any development program will likely be less than can be provided via tax incentives. It seems likely that tax incentives can be used as one element of a broader strategy to encourage private space development, but cannot by themselves accomplish the desired result.

Joint ventures offer the theoretical possibility of combining resources in pursuit of a common goal. However, the substantial difference between private and public sector management paradigms make effective cooperation extremely difficult. If no money changes hands, the requirement of public accountability for the conduct of business by the private entity is eased. However, unless the private-sector partner can obtain a return on investment through effective use of the completed public-private development, attractiveness to investors is not assured. Of further concern is the likely stability of the government commitment.

It may be observed that a true joint venture works well when the contributing partners can establish and respect clear boundaries between the sponsoring and implementing entities. This is more easily achieved between partners of roughly equal status; i.e., government-to-government agreements between sovereign nations, or corporate partners operating according to the strictures of civil law. When partners have inherently unequal status in law and employ significantly different management methods, success is difficult to attain.

Similar to the joint venture, but lacking the need for specific agreement between public and private entities, is the case where public-sector infrastructure is developed and operated with the presumption that private-sector economic activity is thereby facilitated. Obvious examples in the United States and elsewhere include the public road network, public-use airports, and the air traffic control system. No private entity could have developed these systems, but the fact of their public development has enabled a previously unimagined level of private economic productivity. While such examples demonstrate the clear value that can be obtained, the development of common-use infrastructure may fail to provide the direct and immediate stimulus that is sought. For example, the development of interstate highways does not necessarily foster more advanced automotive technology, and an air traffic control system designed around a network of ground-based radio beacons is misplaced in a world with GPS navigation.

A very direct approach to encouraging private sector development in specific areas is the sovereign guarantee of a market for a specific product or service at an established price. This approach rewards winners rather than pre-selecting them, and expends no public funds unless and until the product or service is delivered.

The level at which the price is to be set is a matter requiring considerable care. If the price is set at any level below the marginal cost of the equivalent government-provided service, the requirement of public benefit is met. However, even assuming the private concern conducts operations more efficiently than does the government, such a price may not allow sufficient operating margin for amortization of the initial investment over a reasonable period.

The opposite extreme sets the price at the fully-burdened cost of the equivalent public-sector product. Unless the private concern is less efficient than the government, this price level should allow

amortization of the private investment over a reasonable payback time. However, policy concerns arise in this case because the public benefit is not as easily demonstrated. If public sector capability is to be retained as a hedge against the possibility of contractor failure, price-gouging, surge requirements, or service interruptions of whatever nature, and if the market price is set at the fully-burdened cost to the taxpayer of retaining such capability, then in effect the taxpayer is paying for two sets of investment and infrastructure, one public and one private.

Societies do not generally choose to depend exclusively on the free market where the provision of strategically important goods and services is concerned, especially in a nascent market with few existing providers. Core public-sector institutional capability in such areas is likely to be retained even as efforts are made to develop comparable private sector capacity. In such cases, it is reasonable to set the guaranteed price at a compromise level between the marginal and fully-burdened cost extremes.

Entrepreneurs will always argue that the fully-burdened cost should be used to set guaranteed market prices. Indeed, it is commonly argued (by entrepreneurs) that established companies are "established" only in consequence of the Cold War – an unearned "gift", as it were – and that newer companies should therefore receive similar largess in the form of present-day development funds, which is accommodated by higher market pricing.

In economic terms, this is not rational. The Cold War is a "sunk cost" for all of post-WWII human society, but most especially for the United States and Russia. With that said, those sunk costs clearly did produce certain collateral benefits, among them an aerospace industry that certainly would not have reached its present level of capability in the absence of Cold War tensions. To argue that newer generations of taxpayers should bear additional burdens to re-create capabilities which have previously been created, is to argue for an outcome that is both unfair and inefficient. New resources should go to the creation of new products, not the re-creation of old products by new entities.

Established companies also benefit from higher prices, but possibly not to the extent that they benefit from the barriers to entry that result from lower prices. It is to be expected that various interest groups will argue the merits of whichever policies best serve themselves. The challenge for those who craft those policies is to offer solutions which balance separate interests against larger goals.

If government markets are to be guaranteed for the purpose of helping to bring about new industrial capability, it is the author's view that the market price should be set at a level somewhat below that at which the relevant products and services can be procured from established suppliers. Such a policy encourages established vendors to innovate, or else to furnish goods and services to the public sector at a continuing loss. On the other hand, a guaranteed market price set anywhere close to the established price for which government can obtain service should be a generous target for an entrepreneurial vendor – if indeed that vendor can actually bring to the market the operating efficiency that is universally claimed in the entrepreneur's business plan.

All of these mechanisms, with minor variations, can be found in use in space development programs today, and several would seem to be effective tools to be selectively applied by governments toward the strategic goal of space development. However, it is the present author's view that the provision of guaranteed markets is among the most promising and least utilized of the various approaches.

The NASA Commercial Resupply Services (CRS) contracts for ISS cargo delivery offer a working example of a guaranteed market. However, the analysis presented here demonstrates that the ISS market, whether for cargo or crew or both, is too small and likely too short-lived to bring about the robust commercial space industry that most space development advocates would like to see. The ISS is simply not a program having the strategic scope to provide the required market incentives. Something more is needed.

Let us then consider the logistics requirements for a hypothetical lunar base. Like the ISS, its development and operation will require, broadly, two classes of transportation: one for large and expensive infrastructure and periodic crew rotation, and another for a continuing stream of food, water, light equipment, and other essential but rather conventional items. Transportation for large or unique cargo and for crew will likely be accomplished by means of heavy-lift vehicles; i.e., Saturn V class and larger, for some time to come. These will likely require public-sector development. Other items can be transported on considerably smaller vehicles, if desired, and acquire significant value only by occasion of their placement on the lunar surface.

If a lunar base is sized initially to harbor six crewmembers, then its support requirements will be similar to those of ISS, for which the U.S. share of the obligation is again 15,000 kg/yr. As the base expands – a scenario which is considerably easier to envision than expansion of the ISS – this cargo market must increase.

Lunar surface cargo will be an order of magnitude more valuable, merely by virtue of its location, than ISS cargo. To see why this is so, consider our earlier example of a privately-developed rocket sized to deliver about 9000 kg to ISS orbit. Such a vehicle could deliver about 10,500 kg to a 28.5° orbit, launching due east from Cape Canaveral. We assume this payload to consist of a translunar injection stage and a robotic cargo vehicle. The required total ΔV from LEO to the lunar surface by way of low lunar orbit (LLO) is about 6.0 km/s. That total can be allocated in different ways, but if the translunar stage is sized to deliver 4.1 km/s ΔV using lox/hydrogen with a propellant mass fraction of 0.85 and a specific impulse (I_{sp}) of 445 s, a 3000 kg cargo vehicle can be placed in LLO. This vehicle must supply the remaining 1.9 km/s ΔV required to descend to the lunar surface. If it employs storable propellants with an I_{sp} of 310 s and a propellant mass fraction of 0.8, 1250 kg of cargo can be delivered to the lunar base, inclusive of the tare weight. Thus, at best, less than an eighth of the 10.5 metric tons initially delivered to LEO actually arrives as useful cargo on the moon.

Let us now consider the same private venture as before, except that it is formed to deliver cargo to support a lunar base. For the sake of discussion, we presume that the translunar stage and robotic lander can be developed for the same approximate cost as was assumed for the ISS cargo/crew vehicle. Thus, the NPV of enterprise development expenditures remains $700 M. We again assume the company captures half the lunar logistics market, 7500 kg/yr, but now the delivered price is $590 K in the base year, ten times that for ISS, and begins in Year 6 of the venture, reflecting the greater difficulty inherent in the task.

With our other assumptions held constant, the IRR for the lunar cargo business by itself is over 27%. However, seven launches annually will suffice to deliver this cargo, leaving a half-dozen launches available for other than ISS or lunar payloads. If the company sells these launches at the same $150 M price previously assumed, the IRR increases to about 30.5% for just these two markets. If the ISS cargo mission is undertaken, the $200 M cargo vehicle development must be added to the expenditures, and the enterprise IRR actually drops to about 28.5%.

These conclusions derive from very simple models, but the trend is clear. After exploring two scenarios, the most favorable commercial space venture foreseeable in the near term consists of supplying low-intrinsic-value cargo to a lunar base, not cargo or crew resupply of the ISS.

Moreover, unlike the situation with ISS, such trade could commence as soon as a lunar base location is determined, well before any future human lunar landing. Much lunar cargo will be of such a nature that it can be pre-emplaced years ahead of human missions while remaining valuable. The most obvious example is water, which will always be among the most valuable commodities on the moon. One may imagine the thriving space transportation industry that would evolve, should a government or partnership of governments offer a market price of $590 K in 2012 US$ for the delivery of water in sealed tanks to selected locations on the lunar surface. Similar possibilities may be envisioned for many other commodities and services that would be needed. Thus, a clear commitment by the United States to the leadership of an international lunar base development would, in addition to its numerous other benefits, also provide the most significant foreseeable market for the collateral development of a true commercial space industry.

VI. CONCLUSION

The human development of space can be brought about more effectively than has been the case so far by means of appropriately structured public policies designed to maximize the likelihood of private gain in that development. However, if such enterprises are to be sustainable, care must be taken to establish a proper incentive structure for both parties.

Those who govern must not be, or appear to be, "picking winners"; a sense of transparency and basic fairness must underlie the process by which monies are dispersed. The expenditure of public funds must be accompanied by accountability for expenditures and responsibility for attaining the desired outcome.

Private investors must believe that the political risk of losing their investment is minimal; established programs cannot be cancelled merely because a new head of state is elected, or because the majority party changes in the legislature. Public enterprises can provide an excellent anchor customer for a sustainable private venture, but only government displays a long-term consistency of purpose while

providing a market of sufficient size to make the enterprise worthwhile.

Current U.S. government policies do not achieve these ends. The ISS market is too limited but, in the absence of a serious commitment to any credible subsequent effort, it is "the only game in town". If there is to be a viable commercial spaceflight industry, an anchoring public enterprise of significantly larger scope is necessary. In the author's opinion, development of an international lunar base provides the best near-term option for such a program. To be effective, public policy makers must heed the old investment advice – go big or stay home.

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