S. HRG. 112–501

CONTRIBUTIONS OF SPACE TO NATIONAL IMPERATIVES

HEARING

BEFORE THE

SUBCOMMITTEE ON SCIENCE AND SPACE

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION UNITED STATES SENATE

ONE HUNDRED TWELFTH CONGRESS

FIRST SESSION

MAY 18, 2011

Printed for the use of the Committee on Commerce, Science, and Transportation

U.S. GOVERNMENT PRINTING OFFICE

75–567 PDF WASHINGTON : 2012

For sale by the Superintendent of Documents, U.S. Government Printing Office
Internet: bookstore.gpo.gov Phone: toll free (866) 512–1800; DC area (202) 512–1800
Fax: (202) 512–2104 Mail: Stop IDCC, Washington, DC 20402–0001

SENATE COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

ONE HUNDRED TWELFTH CONGRESS

FIRST SESSION

JOHN D. ROCKEFELLER IV, West Virginia, *Chairman*

DANIEL K. INOUYE, Hawaii
JOHN F. KERRY, Massachusetts
BARBARA BOXER, California
BILL NELSON, Florida
MARIA CANTWELL, Washington
FRANK R. LAUTENBERG, New Jersey
MARK PRYOR, Arkansas
CLAIRE MCCASKILL, Missouri
AMY KLOBUCHAR, Minnesota
TOM UDALL, New Mexico
MARK WARNER, Virginia
MARK BEGICH, Alaska

KAY BAILEY HUTCHISON, Texas, *Ranking*
OLYMPIA J. SNOWE, Maine
JIM DEMINT, South Carolina
JOHN THUNE, South Dakota
ROGER F. WICKER, Mississippi
JOHNNY ISAKSON, Georgia
ROY BLUNT, Missouri
JOHN BOOZMAN, Arkansas
PATRICK J. TOOMEY, Pennsylvania
MARCO RUBIO, Florida
KELLY AYOTTE, New Hampshire
DEAN HELLER, Nevada

ELLEN L. DONESKI, *Staff Director*
JAMES REID, *Deputy Staff Director*
BRUCE H. ANDREWS, *General Counsel*
BRIAN M. HENDRICKS, *Republican Staff Director and General Counsel*
TODD BERTOSON, *Republican Deputy Staff Director*
REBECCA SEIDEL, *Republican Chief Counsel*

SUBCOMMITTEE ON SCIENCE AND SPACE

BILL NELSON, Florida, *Chairman*
DANIEL K. INOUYE, Hawaii
JOHN F. KERRY, Massachusetts
MARIA CANTWELL, Washington
MARK PRYOR, Arkansas
MARK WARNER, Virginia

JOHN BOOZMAN, Arkansas, *Ranking*
ROGER F. WICKER, Mississippi
MARCO RUBIO, Florida
KELLY AYOTTE, New Hampshire

CONTENTS

CONTRIBUTIONS OF SPACE TO NATIONAL IMPERATIVES

WEDNESDAY, MAY 18, 2011

U.S. SENATE,
SUBCOMMITTEE ON SCIENCE AND SPACE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, DC.

The Subcommittee met, pursuant to notice, at 10:36 a.m., in room SR–253, Russell Senate Office Building, Hon. Bill Nelson, Chairman of the Subcommittee, presiding.

OPENING STATEMENT OF HON. BILL NELSON, U.S. SENATOR FROM FLORIDA

Senator NELSON. Good morning.

Just a couple of weeks ago, we celebrated the fiftieth anniversary of human space flight and the first flight into suborbit by Alan Shepard. And then the President's bold statement to go to the Moon within the decade, and that was within 9 years. And that was announced just 3 weeks later.

I remember years ago, when I was a young Congressman, one day I was on the floor of the House, and the Speaker, Tip O'Neill, saw me, and he motioned me over to sit down with him. He knew of my participation in the space program, and he says, "Billy, let me tell you." He says, "One of the times I was a young Congressman from Boston and I was down at the White House," and he said, "I had never seen President Kennedy so nervous." He said, "He was just pacing back and forth like a cat on a hot tin roof."

And he says, "I called over some of his White House aides, and I said, 'What is wrong with the President?'" And they explained to Tip that we were getting ready to launch Alan Shepard on a Redstone rocket. The Soviets had surprised us weeks earlier by putting Gagarin in orbit, and here we were on a rocket that didn't have enough throw weight, save to get that Mercury capsule up into suborbit, and the whole prestige of the United States was on the line.

And of course, the rest is history. Alan Shepard flew. Then Gus Grissom flew, even though his capsule sank in the Atlantic, and he had to swim for it.

In the meantime, the Soviets put up Titov, a second orbital flight. And then, 10 months later, here we put that Mercury capsule on top of an Atlas rocket, and John Glenn climbed in, knowing that it had a 20 percent chance of catastrophe. And then, of course, the rest is history.

These successes in space have become an expression of our technical prowess, announcing to the rest of the world just how capable we can be and how the spirit in this country, this can-do spirit can overcome extraordinary obstacles.

Well, we have enjoyed a steady stream of benefits that have come from the concentrated investments in enabling the technology and producing space applications—basic research, human exploration, Earth observation, national defense—just a few of those that have resulted from us being a leader in the global space economy. And as a result, the spinoffs have improved the livelihoods of all of us earthlings.

The technologies spawned over the last 50 years have changed the way we live. Space-based technologies have become pervasive to the point that many times we don't even realize we are relying on them. And I am just astounded over and over that people say, well, NASA needs to advertise more what it does. Well, NASA does. Every year they put out a book of spinoffs.

And you think about this book being put out for several decades, just how many of those technologies that have spun off have added up. Not only GPS, but look at the data for NOAA and what that has done for weather and prediction of storms. Look at the NASA satellites that complement the Earth-based observations on not only weather, but climate change.

The space assets have changed the way we defend this nation, and they have been integrated into nearly every aspect of the U.S. military as well as the intelligence operations that now we see the fruits of in blending the intelligence community with a surgical military operation. And these benefits, along with the numerous spinoffs and the efficiencies gained through the application of space technology, have provided this nation with a significant return on investment.

Now, we have gathered up some high-powered folks here to talk about the importance of space activities and the contributions of these undertakings to our national priorities. Frank Culbertson, a retired astronaut; captain, U.S. Navy retired. He is a veteran of three space flights and served as the commander of the International Space Station during Expedition 3.

By the way, that is another thing. I am just amazed, Frank, when you talk to people, somehow they have gotten the impression that the space program is being shut down. We have got a Space Station up there that has six astronauts on it. And when the Space Shuttle docks, it is going to have a lot more astronauts on it.

Captain CULBERTSON. Twelve now.

Senator NELSON. And it is 120 yards long. You think looking in the stands of a football stadium down at the field, from one end of the end zone to the other is how big the International Space Station is. And so, we are looking forward to you sharing your experience of logging 146 days in space.

Frank Slazer, Vice President of Space Systems, Aerospace Industries Association. This organization was founded in 1919. It is a leading trade association representing aerospace and defense manufacturers.

Elliot Pulham, Chief Executive Officer of the Space Foundation since 2001. He leads a team providing services to educate and in-

form Government officials, industry, news media, and students about the space industry around the world.

And Dr. Chris Chyba, Professor of Astrophysical Sciences and International Affairs at Princeton, where he directs the Program on Science and Global Security. He was a member of the Review of the U.S. Human Space Flight Plans Committee, also known as the Augustine Committee, and is now a member of the President's Council of Advisers on Science and Technology (PCAST).

So I want to welcome all of you. We are delighted that you are here. We want to get out on the record your thoughts on what we can do for the future. We have a lot of penetrating questions.

I want to turn to our ranking member, Senator Boozman. And then, of course, I want to turn to our colleague, the ranking member of the full committee, Senator Hutchison.

Senator BOOZMAN. With your permission, I will go ahead and yield to my Ranking Member.

Senator NELSON. Of course.

Well, while we are waiting on Kay to approach the microphone, I just want to say the successes that we have had in the NASA bill being passed last year, as well as a lot of the funding that has now implemented the NASA authorization bill, this lady, this young lady is responsible for a lot of that.

So thank you.

STATEMENT OF HON. KAY BAILEY HUTCHISON, U.S. SENATOR FROM TEXAS

Senator HUTCHISON. Well, Mr. Chairman, I thank you. We have worked very hard to try to move NASA forward, and I think that the authorization bill that brought together the need for the commercial investment and the commercial opportunity, along with the use of our workforce that has the experience of so many years in building the rockets and the launchers, that together we believe that we have a good way forward.

And what I hope we can hear from you today is that we need to adhere to the authorization strategy and that that is the way that we should be proceeding. I think the Chairman and I and Senator Boozman and Senator Rockefeller are all very concerned about how slow everything seems to be moving.

And in about a couple of months, we are going to be relying on the Russians to take Americans into space. And we have one more Shuttle that will be going up this summer. But after that, we are looking at maybe 10 years, if we don't really start focusing on this and making better progress, of Russian taxiing our astronauts to the Space Station, where we must use the opportunity for the unique research in that Space Station if we are going to reap the benefits from the investment that we have made.

So I am hoping that we can hear from those of you who do have expertise in this area on how we can move more expeditiously and assure that we get our vehicle up and running sooner rather than later and, second, to fully utilize the Space Station and the research capabilities that it has.

And we have astronauts in space right now, and we are all just wishing them well. We are very excited. It was really this committee that first heard from Dr. Ting about the spectrometer and

the ability to use that for the study of dark energy, the study of the dark matter and the cosmic rays, possibly even for future energy resources, and that excited this committee.

And now, because of the work of many of us on the Committee, including, of course, the Chairman, we are going to see that spectrometer be a part of the Space Station. And so, now we just need to make sure that we can get our astronauts there and on our own ticket, I hope, very soon. And we are going to look to you all to help us figure out how we can move it a little more quickly than it is moving right now.

Thank you very much, Mr. Chairman.

And I do want to also thank Senator Boozman for jumping in on this subcommittee, and he has just been the greatest advocate and quick study. And he is enthusiastic, and we really appreciate you being on the Committee and all you are bringing to it.

Thank you.

Senator NELSON. Senator Boozman?

STATEMENT OF HON. JOHN BOOZMAN,
U.S. SENATOR FROM ARKANSAS

Senator BOOZMAN. Well, thank you. And I appreciate the opportunity to be part of the Subcommittee and to help us move forward.

The Chairman and I were at a meeting this morning, and one of the emphasis at the meeting was that we needed to work together. And I think the relationship that you and—Mr. Chairman—the Ranking Member, Senator Rockefeller, have had in regard with this issue is a great example of that. And this is something that we all agree is so important to our country.

So I really appreciate you, Mr. Chairman, for holding the hearing today to help further inform the subcommittee and the record on the importance of our nation's participation in the global space economy and the tenuous hold that we may have on our position of leadership in that realm.

I am grateful that the Ranking Member of the full Committee, Senator Hutchison, is with us today. Her longstanding dedication and commitment to the Nation's space program is both an example and an inspiration to me, as I settle into the work of this subcommittee as its Ranking Member.

I also want to acknowledge the successful launch on Monday of the Shuttle mission commanded by Mark Kelly. I wish the entire crew of the Shuttle and those already aboard the Space Station success in carrying out this very important mission to expand the scientific capability of this unique national laboratory and provide essential spare and replacement parts and other supplies to ensure the health and vitality of the Space Station systems.

I had the pleasure of going to the Kennedy Space Center at the end of last month for the planned launch of the mission. Unfortunately, the electrical problems with the auxiliary power unit prevented that launch attempt. So I was unable to see the launch.

But my experience during that visit was very meaningful. Not only was I able to see and talk with some remarkable skilled and dedicated workforce, but I was able to see firsthand some of the facilities and features of our Nation's and the world's premier spaceport.

I also was able to sense the spirit and dedication of the workforce, as well as their strong desire to have clear guidance and direction from their agency's leadership, as well as Congress and the administration, for the future. These people know how to do what needs to be done to ensure this Nation's leadership in space, and all they need is direction and resources to go do it. And they need that now.

As you know, Senator Hutchison has noted many times in committee we are at a crucial point of transition in our human space flight programs and are already slipping quickly to a point where our viability to develop and operate a national space launch system will be in doubt. We simply cannot allow that to happen.

The Congress provided a clear path to move the nation away from that precipice in the 2010 NASA Authorization Act. It is past time for the provisions and requirement of that act to be implemented, and I strongly support the Committee's efforts to ensure that that is done.

I look forward to the hearing and the witnesses and more about the great benefits that we receive as a nation from our space program, and a reminder, again, of what is at stake.

And with that, I yield back.

Senator NELSON. Senator Rubio, did you want to make a statement?

STATEMENT OF HON. MARCO RUBIO,
U.S. SENATOR FROM FLORIDA

Senator RUBIO. Mr. Chairman, thank you for holding these hearings on America's space program. They are critically important.

Thank you for the members of the panel for being here at such an important time, as we are nearing the last launch of the Shuttle program and continue to ask ourselves what the future of the space program is for America.

As I reiterate everywhere I go, America's space program is not simply something we do for fun. It has deep commercial impact. It has a significant national security component. And it really helps across industries. I know Senator Nelson will tell you that in Florida, we have all kinds of industries who exist because of the space program. They are spinoffs of things we learned along the way.

The only caveat, and I don't think we will answer that question today, but the only concern that I have—and it is a deep one I think I share with other members of the subcommittee—is where are we headed, literally and figuratively, as a program? What is our goal in the near term and in the long term for the program?

Because I think this program has always functioned best when it knows where it is going, whom it knows where its destination is. Not just the place, but its purpose for existing. And I think the sooner we can have that question answered, the sooner we can fully understand what American space exploration is going to mean in this new century in terms of where we are destined to go and where we want to be, the easier I think it will be to move toward that goal, and I hope that we will make some progress on that during this year.

But thank you for holding these hearings, and thank you to the members of the panel for being a part of it.

Senator NELSON. Thank you, Senator.

OK. I am just going to arbitrarily go by alphabetically. If you all could just keep your comments as much as you can to around 5 minutes? We want to have plenty of time to get into questions.

And so, alphabetically, it would be Dr. Chyba.

STATEMENT OF CHRISTOPHER F. CHYBA, PH.D., PROFESSOR OF ASTROPHYSICAL SCIENCES AND INTERNATIONAL AFFAIRS; DIRECTOR, PROGRAM ON SCIENCE AND GLOBAL SECURITY, PRINCETON UNIVERSITY

Dr. CHYBA. Senator, I was hoping you would begin at the end of the alphabet.

[Laughter.]

Dr. CHYBA. Chairman Nelson, Senator Hutchison, Senator Boozman, Senator Rubio, thank you for giving me the opportunity to testify on this important subject.

In 2009, as Senator Nelson noted, I had the honor of serving on the Review of U.S. Human Spaceflight Plans Committee, which issued its final report in October of that year. The Committee formally ceased to exist on December 2009. So, today, I am speaking solely in my personal capacity, though I do wish to recall some of the Committee's most important findings.

The Human Spaceflight Committee was established to review NASA's program of record and to offer possible alternatives. The Committee examined NASA's planned architecture, the Constellation Program, and concluded that it could not be executed for reasons that were primarily budgetary.

The Committee considered a variety of alternatives. Five principal integrated options were evaluated against 12 metrics, including science knowledge, technology innovation, economic expansion, workforce impact, public engagement, and mission safety. But no architecture would provide missions beyond low-Earth orbit until close to 2030 under the Fiscal Year 2010 budget profile.

But I believe that the most important contribution of our committee's report lies in the framework it suggested for thinking about human space flight. First, the report emphasized that the choice facing us is one of goals, not destinations. The debate over human space flight should not begin as an argument over destination, for example, should we go back to the Moon; or should we go to Mars? Framing the discussion this way risks choosing a destination and then searching for reasons to justify that choice.

The Committee concluded that human spaceflight serves a variety of national interests. Certainly, inspiring the next generation, furthering national security, driving technology innovations, and other areas are important among these. But sending human beings beyond low-Earth orbit with the enormous expense and long timelines that that entails does not make contributions to these areas that are so unique or cost effective that they, in themselves, justify the decision to go beyond low-Earth orbit.

Rather, sending humans beyond LEO has as its fundamental goal charting a path for human expansion into the solar system. This goal embraces the International Space Station as a means to an end, rather than a destination that we have left behind.

Second, the report insists on scientific integrity. Human space flight should not be justified with exaggerated claims about its scientific payoff.

We live in a time of extraordinary discoveries about space. We have learned that early Mars had standing liquid water on its surface and that the resulting sedimentary rocks, which could retain records of early life on Mars, are still accessible. We have learned that there are many other ocean worlds in our solar system—moons of the outer planets that host liquid water oceans beneath their ice covers, oceans that are as big as our own. We have learned that other solar systems are common, and we have learned that most of the mass energy of the universe is not made up of the kind of matter we are familiar with here on Earth and that we don't know quite what this more exotic mass energy is.

Human spaceflight should be an ally in and certainly not a budgetary opponent of these momentous discoveries.

Third, the Committee's report called for the Government space agency to concentrate on the hardest technical problems associated with our goals in space flight. For the rest, including sending astronauts into low-Earth orbit, the commercial sector should play a bigger role. The commercial sector should fill in behind NASA, while NASA spearheads exploration out into the solar system.

And fourth, the Committee's report noted that a problem forever confronting NASA is that it seemingly can have either the budget to develop a new human spaceflight architecture or it can have the budget for ongoing astronaut operations, but not both. To afford a major new launch system, NASA has to stop flying.

This is the ultimate reason for the upcoming gap in U.S. launch access to the International Space Station. Indeed, to develop Constellation, NASA had planned both to stop flying the Shuttle and to terminate the International Space Station in 2016.

The NASA Authorization Act of 2010 declares 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. At this highest level and in many details as well, the 2010 Authorization Act is consistent with our committee's framework.

An important objective identified by the Authorization Act is to "sustain the capability for long-duration presence in low-Earth orbit, initially through continuation of the ISS . . . and through assisting and enabling an expanded commercial presence in, and access to, low-Earth orbit, as elements of low-Earth orbit infrastructure."

There will always be arguments over relative and absolute levels of funding, but the vision in the authorization bill of LEO becoming an economic zone sustained by Government activities, but with increasing commercial opportunities, provides our best chance of bringing costs down and creating a vibrant human space flight future in low-Earth orbit.

Beyond LEO, the 2010 Authorization Act calls on NASA to develop a heavy-lift vehicle to preserve the Nation's core capabilities in space launch and to provide a final backup, should it be needed, for cargo or crew delivery to the ISS. We want to ensure that funding to maintain this core capability does not prevent the development of a commercial ecosystem in LEO that may be our best

longer-term hope for a robust human future in space. If there is one place where new resources should be targeted to mitigate NASA's budget dilemma, it may be here.

To conclude, 40 years later, the decade of Apollo is still remembered as NASA's heroic age. But the NASA of the heroic age was spending almost $20 billion annually in Fiscal Year 2009 dollars on human spaceflight, not $10 billion. Evidently, we are not going to spend $10 billion per year more for human spaceflight. Our committee argued that $3 billion per year more could enable exploration beyond LEO on a reasonable timescale.

Evidently, that, too, is not going to happen. And if not, then experience—our experience of the last four decades—should triumph over hope—and we should embrace a model different from the Apollo model as we move forward.

Thank you.

[The prepared statement of Dr. Chyba follows:]

PREPARED STATEMENT OF CHRISTOPHER F. CHYBA, PH.D., PROFESSOR OF ASTROPHYSICAL SCIENCES AND INTERNATIONAL AFFAIRS AND DIRECTOR, PROGRAM ON SCIENCE AND GLOBAL SECURITY, PRINCETON UNIVERSITY

Introduction

Chairman Rockefeller, Subcommittee Chairman Nelson, Ranking Member Boozman, members of the Subcommittee, thank you for giving me the opportunity to testify on this important subject. In the summer and fall of 2009, I had the honor and responsibility of serving on the Review of U.S. Human Spaceflight Plans Committee (sometimes informally called the "Augustine Committee" after its chair, Norm Augustine), which issued its 156-page final report in October 2009.[1] The committee formally ceased to exist on December 1, 2009.[2] Therefore my testimony today does not (and cannot) represent the views of the Human Spaceflight Committee. I am speaking solely in my personal capacity. Of course, my views are informed by the intensive data-gathering and analysis that our former committee undertook in summer 2009.

The testimony that follows begins by briefly reviewing our committee's mandate, and a few of its programmatic findings and options. A second section presents my own views of the most important characteristics of our report, those that go well beyond programmatics. Media accounts of the report naturally highlighted its programmatic options and implications, yet I believe that the report's most important findings are those framing an overall approach to human spaceflight regardless of details about launch vehicles or crew capsules. The final section of my testimony brings this discussion to bear on the situation today.

I close this introduction with a personal remark. I am a planetary scientist who has been fortunate to be directly involved in the spacecraft exploration of the outer planets, in NASA mission planning, in the search for life in our Solar System, and in the scientific Search for Extraterrestrial Intelligence (SETI). Half of my academic appointment is in astrophysics; the other half is in international affairs and, in particular, nuclear and biological weapons nonproliferation and arms control. I believe that human spaceflight has relevance to both science and security, but I do not consider it to be central to either endeavor. Nonetheless, I support human spaceflight and favor our long-term expansion into the Solar System. One of the ultimate objectives of hearings like this, it seems to me, is to help ensure that the United States, and human civilization, has that future in space.

The Human Spaceflight Committee: Mandate and Programmatic Findings

The Human Spaceflight Committee was established to review NASA's human spaceflight Program of Record and to offer possible alternatives. Its mandate was to provide options, rather than make recommendations, for different possible explo-

---

[1] Norman R. Augustine, Wanda M. Austin, Christopher Chyba, Charles F. Kennel, Bohdan I. Bejmuk, Edward F. Crawley, Lester L. Lyles, Leroy Chiao, Jeff Greason, and Sally K. Ride, *Seeking a Human Spaceflight Program Worthy of a Great Nation,* October 2009.

[2] Electronic mail, subject "Committee Termination," from Philip McAlister at NASA to members of the U.S. Human Spaceflight Plans Committee, December 2, 2009.

ration architectures. This mandate did not include an evaluation of the value of human spaceflight vs. robotic exploration.

The Committee examined NASA's existing architecture for going beyond low-Earth orbit—the Constellation program—and concluded that Constellation could not be executed at planned budget levels. The reasons for this were primarily budgetary. These included that Constellation's Exploration Systems Architecture Study (ESAS) of 2005 assumed that human spaceflight funding would increase until reaching a steady state of about $10 billion per year. But the first post-ESAS budget, the FY 2007 budget, provided significantly lower funding for the Ares I rocket and the Orion crew vehicle than ESAS had anticipated. Pushing programs out into the future always increases costs. Differences between anticipated and actual budgets, plus technical problems in the Ares I and Orion programs, had significant impact. The FY 2009 budget was lower than that anticipated by ESAS by at first $1 billion per year, and then lower with a growing disparity that reached $2 billion per year in the steady state. The FY 2010 President's Budget Submittal was lower still, anticipating a final steady state level of funding of about $7 billion per year—some $3 billion below the annual $10 billion against which ESAS had originally planned.

Moreover, it was intended that Shuttle would complete its final flight in 2010, and that the International Space Station (ISS) program would be terminated in early 2016, with corresponding savings becoming available for Constellation. But the ISS termination itself was not budgeted. Yet termination would have to entail the safe de-orbiting of this 350 metric ton structure, requiring either the design, construction and flight of a new de-orbit module to accomplish this task, or the piecemeal de-orbit of the structure via disassembly.[3] Taking all this into account, the Human Spaceflight Committee concluded that under the FY 2010 funding profile, the Constellation program would at the least be greatly stretched out in time. The planned heavy-lift vehicle (Ares V) would not be available until the late 2020s, and lunar return could not occur until well into the 2030s, if at all. In short, the Constellation program was not executable at its existing budget.

The Committee considered a variety of integrated scenarios: Constellation and variations thereof; less demanding returns to the Moon; and a scenario of increasing deep-space capability that it called "the flexible path." Five principal integrated options (with sub-options) were evaluated against twelve metrics, including science knowledge, technology innovation, economic expansion, workforce impact, public engagement, and mission safety.[4] The flexible path had the budget profile advantage of not requiring the simultaneous development of both heavy-lift capability and lunar-landing vehicles. But no architecture would provide missions beyond LEO until close to 2030 under the FY 2010 budget profile.

In historical context, this is not surprising. A plot of the human spaceflight annual budget (in FY 2009 dollars) through time shows a sustained peak during the Apollo years in the 1960s of nearly $20 billion per year. That budget is now, and has been for nearly two decades, at a level of half this or less. The Committee concluded that sending astronauts beyond LEO in the 2020s would require ramping up to a steady-state augmentation of NASA's budget by some $3 billion per year.

Beyond Programmatics

I believe that the most important contribution of the U.S. Human Spaceflight Committee report lies neither in its finding that the Constellation program was not executable at its existing budget, nor in its options for future programs, but in the framework it suggested for the future of human spaceflight. This framework provides the lens through which I view the current situation.[5]

---

[3] The Committee requested an independent assessment of this task, and found projected costs of $2 billion or more, depending on the method of de-orbiting required. Augustine *et al., Seeking a Human Spaceflight Program,* p. 54.

[4] A Mars-first scenario had also been considered, but was evaluated to be so expensive that it did not make sense to examine it out to this level of detail. The five options considered (along with sub-variants) were a baseline case, founded on the Constellation program, a case in which ISS was extended and the development of Ares I was foregone, lunar-oriented strategies, and flexible-path strategies. The twelve metrics used for evaluation were exploration preparation, technology innovation, science knowledge, expanding and protecting human civilization, economic expansion, global partnerships, public engagement, schedule and programmatic risk, mission safety challenges, workforce impact, programmatic sustainability, and life-cycle cost. See Augustine *et al., Seeking a Human Spaceflight Program,* Chapter 6, "Program Options and Evaluation."

[5] The discussion in this section draws, in part, on a McClatchy-syndicated op-ed the author published in late November 2009. See, for example, Christopher Chyba, "Report Provides Roadmap for Human Space Flight," *Cleveland Plain Dealer,* November 29, 2009, available at *http://www.cleveland.com/opinion/index.ssf/2009/11/report__provides__roadmap__for__hu.html*.

First, the report emphasized that the choice facing us is one of *goals, not destinations.* The debate over human space flight should not begin as an argument over destination—for example, "Should we go back to the Moon?" or "Should we go to Mars?" Framing the discussion this way risks choosing a destination first, then searching for reasons to justify that choice. At least in part, that is what went wrong with the International Space Station, a destination in low-Earth orbit (LEO) that is still searching to explain its purpose.[6]

That the Station's purpose was difficult to identify is demonstrated, I believe, by the Constellation program's intention to simply terminate Station in early 2016—almost immediately after its completion. Dropping the ISS into the ocean upon completion suggests that it was viewed as no more than a gigantic white elephant. But such a plan makes some sense, in a disheartening way, if one's destination had once been the Station itself, but now one's destination has shifted, say, to the Moon. (Even in this context the plan is questionable, since the diplomatic price that would have been paid with our Station partners would have been steep, and this would have damaged our prospects for future international cooperation in lunar return.)

Instead, the Human Spaceflight Committee report argued that we should decide on our goals for human space flight, and then have destinations flow from these goals. The committee concluded that human space flight serves a variety of national interests—and certainly inspiring the next generation, furthering national security, driving technology innovation, and other areas are important among these. But sending human beings *beyond low-Earth obit,* with the enormous expense and long timelines that this entails, does not make contributions to these areas that are so unique or cost effective that they in themselves justify the decision to go beyond LEO. Rather, sending humans beyond low Earth orbit has as its fundamental goal charting a path for human expansion into the Solar System. This is ambitious, but if this is not our goal, we'd best just restrict ourselves to destinations in LEO. Human expansion into the solar system is a goal worthy of a great nation working in concert with other space powers. Choosing this as our long-term goal, while trying to maximize spaceflight's contributions to all areas of society as we proceed, provides the context for making decisions about our next steps. And it also embraces the ISS as a means to an end rather than a destination that we've left behind.

Second, the report insists on *scientific integrity.* Each option presented for consideration was examined for its impact on science, and all else being equal options that did a better job furthering science were rated more highly. But human spaceflight should not be justified with exaggerated claims about its scientific payoff. Exploration with astronauts can have significant scientific benefits in several areas beyond the tautological justification of studying what happens to humans in space. As was emphasized by scientists' testimony to the Committee, astronauts have a tremendous advantage over robot spacecraft when it comes to field geology in particular. The ability to pick up a rock, turn it over, expose a fresh surface with a hammer and then use geological expertise to decide whether to move on or instead to "dig in" and examine the current site in detail is a human capability that far exceeds anything robot rovers can currently do. In a similar way, the ability to service and repair space observatories that face unanticipated problems favors the astronaut over the robot.

But astronauts are also far more expensive than robot spacecraft or rovers, and have their greatest advantage in the most complex environments and circumstances. Mars is the most complicated surface environment we will face in the foreseeable future, so it is where astronauts will provide the greatest advantage. But it will be decades before humans walk on that world—if we are lucky—and for most other science in space, humans often get in the way.

Moreover, if NASA's space science budget is not protected, it could be raided to fund cost overruns in the human program. Human spaceflight, if it is to be justified and sustained, needs to be aligned with national priorities. Were key space-based research to be cut to fund human spaceflight, human spaceflight would be put into opposition with those priorities. This would serve neither science nor the future of human spaceflight well.

We live in a time of extraordinary discoveries about outer space. We have learned that early Mars had standing liquid water on its surface, and that the resulting sedimentary rocks are still accessible. These are the kind of rocks that can contain information about the early martian environment, or even microfossils should life ever have existed on that world. We've learned that there are many other ocean worlds in our Solar System—moons of the outer planets that host liquid water oceans be-

[6] "*Because NASA does not have a compelling vision for how it will use the ISS, many American citizens do not have a clear idea of what it is for.*" Augustine *et al., Seeking a Human Spaceflight Program,* p. 56. Italics in the original.

neath their ice covers that are as big as our own. We've learned that solar systems are common, and that the arrangement of planets in our own is but one of a vast array of possibilities. And we've learned that most of the mass-energy of the Universe is not made up of the kind of matter we are familiar with here on Earth—and that we don't quite know what this more exotic mass-energy is. Human spaceflight should be an ally in, and certainly not an opponent of, these momentous discoveries.

Third, the Human Spaceflight Committee report called for the government's space agency to concentrate on the hardest technological problems associated with our goals in space flight. For the rest, including sending astronauts into low-Earth orbit, *the commercial sector should play a bigger role.* The commercial sector should "fill in" behind NASA, while NASA spearheads exploration out into the Solar System. In fostering a robust commercial sector, NASA's role would include funding, in a disciplined way, the development of capabilities by a number of commercial actors, developing the technologies to underpin future exploration, and providing an ongoing market pull for the commercial sector by providing destinations—whether this is the ISS or destination projects, such as the development and implementation of potentially game-changing capabilities such as fuel depots in space.

Fourth and finally, the Committee report called for *budget and schedule reality.* The report argued that the budget then foreseen for human spaceflight—$99 billion over ten years—would not allow NASA to do anything beyond low-Earth orbit. NASA could afford to pay for the new rockets and crew vehicle that would replace the space shuttle and make it possible to journey outward, but not for systems to land on the Moon or for operations on a path to take astronauts to asteroids or to fly around Mars. The report suggested that in order to do both—to develop the new systems and to fly them to destinations beyond low-Earth orbit—would require an increase in NASA's budget of around $3 billion per year.

A problem forever confronting NASA is that it seemingly can have either the budget to develop a new human spaceflight architecture, or it can have the budget for ongoing astronaut operations—but not both. To afford to develop a major new launch system, NASA has to stop flying. This is the current budget dilemma in a nutshell, and the ultimate reason for the upcoming "gap" in U.S. launch access to the ISS. Indeed, to develop Constellation, NASA planned both to stop flying the Shuttle and to terminate the ISS.

You might also notice that the Human Spaceflight Committee's report contained few inspiring artists' conceptions of our dramatic future with human explorers in space. Some past reports have been full of pictures of rocket launches, space cities, and astronauts with rocket packs flying all over. I respect those reports' optimism, and want to share it. But there have been too many glorious images of our exciting future in space unmatched by the budget for a realistic path to that future.

Current Issues

The NASA Authorization Act of 2010 declares that "The long term goal of the human spaceflight 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."[7] At this highest level, and I believe in many details as well, the 2010 Authorization Act is consistent with the sense of the Human Spaceflight Review Committee's framework.

An important objective identified by the Authorization Act is to "sustain the capability for long-duration presence in low-Earth orbit, initially through continuation of the ISS . . . and through assisting and enabling an expanded commercial presence in, and access to, low-Earth orbit, as elements of a low-Earth orbit infrastructure. . . ."[8] The bill embraces the development of commercial cargo (Commercial Orbital Transportation Services, COTS) and crew (Commercial Crew Development, CCDEV) capabilities. There will always be arguments over relative and absolute levels of funding, but the vision in the Authorization bill of LEO becoming an economic zone (from the point of view of human spaceflight; of course it is this already with respect to unmanned satellites) sustained by government activities (*e.g.,* servicing ISS, development of new capabilities such as fuel depots) but with increasing commercial opportunities, provides our best chance at bringing costs down and creating a vibrant human spaceflight future in low-Earth orbit. The COTS model in which NASA pays the commercial providers by milestones, rather than in a cost-plus manner, already suggests that this new approach brings concrete advantages.

[7] "National Aeronautics and Space Administration Authorization Act of 2010," Pub. L. No. 111–267 (Oct. 11, 2010), Section 202(a).
[8] *Ibid.,* Section 202(b).

Beyond LEO, at this point the government must take the lead in developing deep-space capabilities, but we can do so with the hope that the commercial model may ultimately mature to the point where it can play a role analogous to the one it is just beginning to play in low-Earth orbit. That remains to be seen, but the optimists' view of our future in space is that this, too, will prove credible. For now, the 2010 Authorization calls on NASA to develop a heavy-lift vehicle to preserve the Nation's core capabilities in space launch, and to provide a kind of final backup, should it be needed, for cargo or crew delivery to the ISS in the event that other commercial or partner-supplied vehicles fail to meet these needs.

NASA is to build as much as practical on existing capabilities and create a heavy-lift vehicle in the 70–100 tons-to-orbit range. This system is to be evolvable to a 130-ton-to-orbit system.[9] However, the Authorization bill also states that: "Human space flight and future exploration beyond low-Earth orbit should be based around a pay-as-you-go approach. Requirements in new launch and crew systems authorized in this Act *should be scaled to the minimum necessary to meet the core national mission capability needed to conduct cislunar missions.* These initial missions, along with the development of new technologies and in-space capabilities can form the foundation for missions to other destinations. These initial missions also should provide operational experience prior to the further human expansion into space."[10] We should not lose sight of this "minimum necessary requirements" criterion, and do our best to ensure that funding to maintain this core national capability does not prevent or overly impede the development of the commercial ecosystem in LEO that may be our best longer-term hope for a robust human future in space. If there is one place where new resources should be targeted to mitigate NASA's budget dilemma, it is here.

Conclusion

Forty years after Apollo, the decade following President Kennedy's pledge to land a man on the Moon is still remembered as NASA's heroic age. We cannot help but admire the achievements of that time. But it may be that the power of this memory and admiration can also work against us. It is sometimes said that NASA isn't the agency that it was in 1965. But in FY 2009 dollars, that agency then was spending nearly $20 billion, not $10 billion, per year on human spaceflight.

Twice since Apollo, U.S. Presidents have announced Apollo-like projects. President George H. W. Bush declared his Space Exploration Initiative in 1989 to send astronauts to Mars, but no corresponding budget was forthcoming. President George W. Bush announced his Vision for Space Exploration in 2004, but the budget not only was not sustained, it was not quite there from the beginning. We should learn from the four decades after Apollo as much as from the decade of Apollo. And the lesson of those four subsequent decades seems to be that we cannot hope to be successful by declaring new Apollo-like programs for space exploration.[11]

All the dramatic artists' renditions in our reports or powerpoint slides won't make it so. We are not going to spend $10 billion per year more for human spaceflight. Our Committee argued that $3 billion per year more could enable exploration beyond LEO on a reasonable timescale. Evidently that, too, is not going to happen. If not, then experience should triumph over hope and we should embrace a different model.

That model would be one where we systematically assemble the capacity and infrastructure that will, over time, enable our expansion into the Solar System. We would maintain key national capabilities and develop the heavy-lift capacity that will be needed—and develop it in a way that is evolvable to greater demands in the future. But we would also strongly support the robust growth of a space-launch-to-LEO "ecosystem" of cargo and crew capabilities, and recognize this as a model for the future that we want to encourage. Synergistically, NASA would develop technologies that might prove to be game-changers, or at least game-evolvers, such as fuel depots in low-Earth orbit or beyond. We would work toward human operations in cislunar space,[12] then move out. But this time, as we went, we would try to create a human spaceflight ecosystem in the wake of our exploration. Let's see if we can.

---

[9] *Ibid.,* Section 302(c).

[10] *Ibid.,* Section 301(a)(7). Italics are mine.

[11] See Roger Handberg, "Small Ball or Home Runs: The Changing Ethos of U.S. Human Spaceflight Policy," *The Space Review,* January 17, 2011, available at *http://www.thespacereview.com/article/1759/1.*

[12] "Cislunar" space is defined to be the region of space around Earth and out to and including the region of space around the surface of the Moon.

Senator NELSON. Thank you, Dr. Chyba.

So now we are at $18.5 billion per year, projected flat line for at least a few years. So that is the constraints we are looking at.

Dr. CHYBA. For the entire agency. Yes, sir.

Senator NELSON. Yes.

Captain Culbertson?

STATEMENT OF FRANK L. CULBERTSON, JR. (CAPTAIN, USN, RET.) COMMANDER, INTERNATIONAL SPACE STATION EXPEDITION 3

Captain CULBERTSON. Thank you.

Good morning, Chairman Nelson, Ranking Member Hutchison, Ranking Member Boozman, and Senator Rubio.

I appreciate this opportunity to discuss the significant and tangible contributions of the space program to our national imperatives and the vital need to maintain our leadership on this endless frontier, especially since this hearing occurs in the same month we commemorate the fiftieth anniversary of Alan Shepard's first American space flight and President Kennedy's speech to Congress committing our nation to land on the Moon.

I had the privilege and honor on two Space Shuttle missions and one expeditionary mission to the International Space Station of logging 144 days in space. And while it is true that every day spent in space is memorable, there was 1 day while onboard the International Space Station that will remain seared in my memory as long as I live. And you will see in a moment why I refer to this.

To me, this day serves as a constant reminder of why America's commitment to peacefully explore and utilize space for the benefit of our citizens and people around the world is so vital to our collective future and why we must not retreat from our leadership in space, especially in light of recent events.

Ten years ago, I was serving as commander of the third expedition aboard the ISS and was the only American physically in orbit. On the morning of September 11, 2001, I had just completed medical examinations on my fellow crew, Vladimir Dezhurov and Mikhail Tyurin, and called our flight surgeon with the results. Dr. Hart replied with the chilling words, "Frank, we are having a very bad day down here on the ground."

We were stunned as he described events in New York City, Washington, D.C., and Pennsylvania as they unfolded. I saw that our flight path was taking us over New England. So I was able to grab a video camera and focus in horror on the spreading smoke and dust enveloping Manhattan. In a few hours, we found out that we had just witnessed the second tower's fall.

Later, after being assured by my wife, with NASA's help, that our scattered children were safe, I learned sadly that the captain of American Airlines Flight 77, which crashed into the Pentagon, was my Naval Academy classmate, fellow fighter pilot and friend, Chic Burlingame. It became very personal to me at that moment.

The next night, I wrote a personal letter to my academy classmates, who were gathering for our long-planned reunion. The letter concluded with, "It is horrible to see smoke pouring from wounds in your own country from such a fantastic vantage point. The dichotomy of being on a spacecraft dedicated to improving life on the

Earth and watching life being destroyed by such willful terrible acts is jolting to the psyche, no matter who you are. And the knowledge that everything will be different than when we launched by the time we land is a little disconcerting."

"I have confidence in our country and in our leadership that we will do everything possible to better defend her and our families and to bring justice for what has been done."

My confidence that justice would be served began a month later, as I observed the invasion of Afghanistan from space, as my classmates and friends entered harm's way to punish those who had harmed us, and was even better fulfilled three weeks ago. The dichotomy I wrote about after September the 11th between a vile and doomed ideology bitterly opposed to freedom and progress and our peaceful venture to utilize the International Space Station for the noblest of human purposes serves as a useful point from which to discuss the critical need to have a strong and vibrant space program.

As I said, everything was different after we landed, but also different onboard. We had a job to do, as did the brave and committed team on the ground, but our relationship with the ground changed. We spoke with and to an even larger number and variety of people than had been planned preflight, from royalty and prime ministers to special people, such as Walter Cronkite—twice, because he had more questions—and school children displaced by the events at Ground Zero. I spoke to over 40 schools during the time I was up there.

Always it was as if they were looking to us to prove that humanity can build together, can do great things, even in the midst of the unthinkable. You see, they wanted to look to the sky for an example of something good, something positive they could point to for others. An international project worth pointing your children toward. And they wanted to hear that the world still looked OK from up there.

Some in this room were around when we went to the Moon from 1969 to 1972 in the midst of that other war, Vietnam, and while trying to heal wounds and solve issues with civil rights and civil liberties in our own country. It was an extremely difficult time, but we still had the ability and the courage to expand our boundaries in space while changing society on Earth and dealing with the reality of that conflict.

And everyone remembers the significance of the Moon landing and how proud it made them to be alive at a time like that. It proved that despite the biggest challenges we can imagine on Earth, we can still do great things. We can maintain our leadership and do great things beyond the Earth, beyond the horror we have to deal with day-to-day.

Today, we should be equally proud that we now have a permanent presence in space, a place for our children to aspire to work and to use as a stepping stone to their own new boundaries. The Space Station has been permanently manned for over a decade.

The International Space Station, which NASA Administrator Charles Bolden rightly calls the centerpiece of our human spaceflight endeavors for the coming decade, our anchor for human exploration, is not only one of the most amazing feats of human en-

gineering, but also one of the greatest examples of productive international cooperation.

Through use as a research facility will improve the lives of millions and help pave the way for humanity's next great leaps to the Moon, to the asteroids, and onward to Mars. Space exploration currently led by the United States of America is the true march of progress.

The ISS, a cooperative project between the U.S., Canada, the nations of the European Space Agency, Japan, and Russia, is a tremendous example of soft power. The ability of the United States and our partners to expand our influence and capabilities because of the attractions of our values, goals, and technological leadership.

I was well aware of that type of power projection as a career naval officer and saw the benefits of it in port of calls to almost 40 countries around the globe. As the second manager of the Shuttle-MIR Program, the precursor to the ISS, I also saw the incredible benefits of partnering with our former adversaries, learning their capabilities, and together beginning to build the station that has provided humanity with a permanent presence in orbit for the past decade.

I believe the ISS is an ideal platform for conducting valuable scientific research and developing and simulating the operations, technologies, and techniques for executing more ambitious and lengthy missions to the Moon, Mars, and other destinations.

This morning, Endeavour, my last ride home from space, docked with the Space Station for the last time. The crew of Endeavour and the crew of the Space Station are working together now to continue the job that was begun many, many years ago.

I want to, at this time, give my tribute to the Shuttle team that has made all of this possible for so long. The dedication and the commitment, the long hours, the do-overs, the listening to the public, the listening to the media, criticism and praise, they have done a fantastic job. My hat is off to them.

But like almost all the military aircraft I flew and all the aircraft carrier I landed on, the Shuttle is ending its mission. All my former aircraft are now static displays, and my aircraft carriers are museums. This happens, and now we are transitioning to a new phase.

ISS is now outfitted with 15 pressurized modules, the volume of a five-bedroom house. To give you an example of its scope, the solar array that powers the facility at 84 kilowatts has a surface area that could cover the U.S. Senate chamber three times over. Some of you suggested they do that.

[Laughter.]

Captain Culbertson: The ISS capabilities include 34 research racks and 22 external locations for experiments. It is now capable of accommodating 100 to 300 payloads with crew science support of 2,000 or 3,000 hours a year.

Even though we are just reaching the point of near full assembly and the full potential can be utilized, research has already demonstrated its promise, and my written statement contains several references to all that has been done up there and is being done on Earth.

But it will require in the future a robust system for both resupply and crew transport. We can debate the timetable we are on, the

details of who provides what, but in the end, NASA and the U.S. space industry are aggressively pursuing systems that will—no, must be safe and reliable.

A combination of commercial endeavors and government endeavors will need to work to make a balance of research for long-duration human space flight with frequent visits by experimenters and observers. I personally think we need to go to the station as often as possible with as many spacecraft as we can.

This will require the solid support of Congress, government leaders, and the American people. And the authorization bill, I think, moves us in that direction.

With respect to how much we invest in the space program, I would imagine that members of the Committee probably share my frustration. The survey shows the public vastly overestimates NASA's budget. Yet this is somewhat understandable, given the high profile of the missions.

I was simply astounded the other day, however, when I read a recent Congressional Quarterly cover story on the space program in which the author wrote that NASA's budget has hovered at around 1 percent of the total budget since the mid-1970s. If only that were the case.

Alas, the reality is that today NASA's budget represents less than 0.5 percent of the budget. If it were a mere 1 percent, actually, we probably wouldn't have to have this hearing.

Finally, a discussion of NASA's contributions to national imperatives must include the subject of which nation will be the first among nations in leading peaceful human and robotic exploration of the solar system while learning how to live and travel more safely, efficiently, here on Earth.

It is not a foregone conclusion that the United States will remain the preeminent space-faring nation and will reap the benefits of leading the march of progress toward low-Earth orbit. That is why I am gratified that this hearing is being held, and I am honored to sit alongside people who care as deeply about our future in space as I do.

In closing, I am proud that our nation continues to inspire people throughout the world. My mother and father's generation after World War II took on responsibility of leading the world as a great nation. They assumed the leadership. They assumed the responsibility.

But when you assume that responsibility, a lot goes with it. And to me, the space program is a part of that responsibility. You have to set an example. You have to shine a light on the unknown, and you have to put beacons in the sky, such as the International Space Station, which can easily be seen with the naked eye. Great nations do great things. We need to continue doing that.

I feel a special responsibility, because of my unique position as the only American who was off the planet on September 11, to spread the world that our leadership in space is vital to our way of life and our future. It is a hard-won accomplishment and one we should never consider surrendering easily.

In space, we inspire respect and sometimes envy, but always we show we are leading. Our freedoms allow us to do that. This, to me, is the abiding lesson of my unique experience.

Thank you for the opportunity to testify before this important hearing.

[The prepared statement of Captain Culbertson follows:]

PREPARED STATEMENT OF FRANK L. CULBERTSON, JR. (CAPTAIN, USN, RET.)
COMMANDER, INTERNATIONAL SPACE STATION EXPEDITION 3

Good morning Chairman Nelson, Committee Ranking Member Hutchison, Ranking Minority Member Boozman and members of the Subcommittee. I appreciate this opportunity to participate in this very timely hearing concerning the ongoing significant and tangible contributions of the space program to our national imperatives, and the vital need to maintain our leadership on this endless frontier, especially since it occurs in the same month we commemorate the 50th anniversary of Alan Shepard's first American Spaceflight and President Kennedy's speech to Congress committing our Nation to land on the moon.

I had the privilege and honor on two Space Shuttle missions and one expeditionary mission to the International Space Station, of logging 144 days in spaceflight. And while it is true that every day spent in space is memorable, there was one day while onboard the International Space Station that will remain seared in my memory as long as I live. To me this day serves as a constant reminder of why America's commitment to peacefully explore and utilize space for the benefit of our citizens and people around the world is so vital for our collective future, and why we must not retreat on our leadership in space.

Ten years ago, I was serving as commander of the Third Expedition onboard the ISS, and was the only American physically in orbit. On the morning of September 11, 2001, I had just completed medical examinations of my fellow crew, Vladimir Dezhurov and Mikhail Tyurin, and called our flight surgeon with the results. Dr. Hart replied with the chilling words, "Frank, we're having a very bad day here on the ground. . . ." We were stunned as he described events on the ground in New York City, Washington, D.C. and Pennsylvania as they unfolded. I saw that our flight path was taking us over New England, so I was able to grab a video camera and focus, in horror, on the spreading smoke and dust enveloping Manhattan. We found out in a few hours that we had just witnessed the fall of the second tower. Later, after being assured by my wife that our scattered children were safe, I learned sadly that the Captain of American Airlines Flight 77, which crashed into the Pentagon, was my Naval Academy classmate, fellow fighter pilot and friend Chic Burlingame.

The next night, I wrote a personal letter to my Academy classmates gathered for our long-planned reunion. The letter concluded with, "It's horrible to see smoke pouring from wounds in your own country from such a fantastic vantage point. The dichotomy of being on a spacecraft dedicated to improving life on the earth and watching life being destroyed by such willful, terrible acts is jolting to the psyche, no matter who you are. And the knowledge that everything will be different than when we launched by the time we land is a little disconcerting. I have confidence in our country and in our leadership that we will do everything possible to better defend her and our families, and to bring justice for what has been done."

My confidence that justice would be served began a month later as my classmates and friends entered harm's way to punish those who harmed us—and was even better fulfilled three weeks ago. The dichotomy I wrote about after September 11th between a vile and doomed ideology, bitterly opposed to freedom and progress, and our peaceful venture to utilize the International Space Station for the noblest of human purposes serves as a useful point from which to discuss the critical need to have a strong and vibrant space program.

As I said, everything was different after we landed, but also different on board. We had a job to do, as did the brave and committed team on the ground, but our relationship with the ground changed. We spoke with and to an even larger number and variety of people than had been planned preflight—from royalty and prime ministers to special people such as Walter Cronkite (twice) and school children displaced by the events at Ground Zero. Always, it was if they were looking to us to prove that humanity can build together, can do great things, even in the midst of the unthinkable. It seemed they wanted to look to the sky for an example of something good, something positive they can point others to: an international project worth pointing your children toward—and they wanted to hear that the world still looked okay from up there.

Some in this room were around when we went to the moon from 1969 to 1972, in the midst of that other war—Vietnam—and while trying to heal wounds and solve issues with civil rights and civil liberties in our own country. It was an ex-

tremely difficult time, but we still had the ability and courage to expand our boundaries in space while changing society on earth and dealing with the realities of a conflict. And everyone remembers the significance of the moon landing, and how proud it made them to be alive at a time like that.

Today we should be equally proud that we now have a permanent presence in space, a place for our children to aspire to work, and to use as a steppingstone to their own new boundaries. The International Space Station, which NASA Administrator Charles Bolden rightly calls "the centerpiece of our human spaceflight endeavors for the coming decade, our anchor for human exploration," is not only one of the most amazing feats of human engineering, but also one of the greatest examples of productive international cooperation, whose use as a research facility will improve the lives of millions and help pave the way for humanities' next great leaps to the moon, to the asteroids and onward to Mars. Space exploration, currently led by the United States of America is the true march of progress.

The ISS, a cooperative project between the U.S., Canada, the nations of the European Space Agency, Japan and Russia, is a tremendous example of "soft power"—the ability of the United States and our partners to expand our influence and capabilities because of the attraction of our values, goals, and technological leadership. I was well aware of that type of power projection as a career Naval officer and saw the benefits of it in port calls to almost forty countries around the globe. As the second manager of the Shuttle-Mir Program, the precursor to ISS, I also saw the incredible benefits of partnering with our former adversaries, learning their capabilities, and together, beginning to build the station that has provided humanity with a permanent presence in orbit for the past decade.

In addition, I believe the ISS is an ideal platform for conducting valuable scientific research and for developing and simulating the operations, technologies, and techniques for executing more ambitious and lengthy missions to the Moon, Mars, and other destinations.

Outfitted with 15 pressurized modules the ISS has the volume of a five-bedroom house. To give you one example of its scope, the ISS solar array that powers the facility at 84 kw, has a surface area that could cover the U.S. Senate Chamber three times over. The ISS's capabilities include 34 research racks and 22 external locations for experiments. The Station is capable of accommodating 100–300 experimental payloads with crew science support of at least 2,000 to 3,000 hours per year.

When I returned to Earth from the Expedition-3 mission I came home on the Space Shuttle Endeavour. And this morning, the Endeavour—now on its final voyage—is once again at the International Space Station, adding to its capabilities with delivery of the Alpha Magnetic Spectrometer, a particle physics experiment that will measure cosmic rays and in an example of science at its most daring look for evidence of dark matter and antimatter in the far reaches of the universe. This scientific instrument owes its place on the space station directly to actions taken by the Senate.

Even though we are just reaching the point of near full assembly and the full potential of the ISS can begin to be utilized, research onboard the Station has already demonstrated its promise. Thus far there have been 214 published results from specific payloads and projects, and 20 publications on the ISS and future exploration technologies. I am very thankful this facility will operate at least up to the end of this decade and perhaps to 2028.

A few examples illustrate the stations promise. One of the most compelling ISS research results is confirmation that the ability of common germs to cause disease increases during spaceflight, but that changing the growth environment of the bacteria can control this virulence. An experiment identified the increased virulence of space-flown Salmonella typhimurium, a leading cause of food poisoning. Future ISS research will target a vaccine for this disease.

Another ISS experiment demonstrated a new and powerful method for delivering drugs to targets in the human body. Microgravity research on the station led to the development of miniature, liquid-filled balloons the size of blood cells that can deliver medicine directly to cancer cells.

The work to develop the Station's regenerative water recycling system to provide safe drinking water for crews onboard the Station has resulted in technology that can help in disaster recovery in areas where water purification is a significant issue after earthquakes and other natural disasters. The system has been used to provide purified water to Kurdish villages in Northern Iraq and for earthquake relief in Pakistan.

In a different area of research, ISS tests of how spacecraft materials withstand the harsh space environment have been used to develop longer duration solar cells and insulating materials for future commercial station cargo ships. This experiment has significantly reduced the time needed to develop new satellite systems, and

paved the way for materials to be used in new NASA spacecraft that will send crews beyond Low Earth Orbit.

In one of my favorite examples, NASA built a facility at its Glenn Research Center to bombard materials planned for the ISS with atomic oxygen to test their durability. Atomic oxygen is an elemental form of oxygen that does not exist in Earth's atmosphere, but is common in Low Earth Orbit, and is known to corrode spacecraft. NASA engineers Bruce Banks and Sharon Miller realized their facility could be used to remove unwanted material from surfaces without ever needing to touch or rub them. Their invention was used to restore two 19th century religious paintings damaged by an arson fire at St. Alban's Church in Cleveland Heights, Ohio, and a vandalized Andy Warhol painting.

I'm confident that these promising research results are only the start of what we are going to see come out of ISS research. And thanks to the work of this committee and others in Congress, the 2005 NASA Authorization Act designated the U.S. segment of the ISS as a National Laboratory. This designation will enable a non-profit organization to allocate valuable ISS experimental space for the most promising research proposals in the fields of biology, chemistry, medicine, physiology and physics as well as for astronomical and meteorological observation. The non-profit will invite research proposals from NASA, other governmental organizations, university researchers or the private sector.

I personally see the ISS as, at least, the virtual jumping off point for us to begin to send crews out to explore further in the solar system. And frankly, I wish we would be more aggressive in getting more crews up there to conduct more research.

The ISS is a vital research platform to understand the effects of the space environment on humans, with research aimed at protecting future explorers from the harmful effects of radiation in space, and to reduce the rate of bone and muscle loss that astronauts experience over lengthy periods of time in zero gravity. The ISS serves as a test-bed for developing spacecraft hardware and closed-loop life support systems, and to test operations for missions that will extend for millions of miles and years at a time. ISS crews will simulate our next great leaps in space, and help mature our understanding of human factors and the ability of explorers from diverse backgrounds to work in concert with each other in close-quarters for extensive periods of time. The ISS will help us learn the skills of deep space logistics management, conducting remote medicine and managing communications when contact with Mission Control is minutes rather than seconds away.

With this knowledge we can be confident when the time does come to return humans to the Moon, to explore the asteroids, and eventually land on the surface of Mars.

Of course all this will be true only if we have Federal policies that support a robust space program over a sustained period of time, if we maintain a highly-skilled and dedicated workforce, and if we continue to inspire the next generation of explorers to aim high for goals worth striving for.

NASA has been looking for innovative ways to develop new capabilities in space and has developed a government-private industry partnership for providing logistical support to the ISS. That partnership, the Commercial Orbital Transportation Services program, or COTS, will come to fruition in the very near future with new ground and space infrastructure to support ISS operations well into the future at a cost significantly less than the cost of a traditional government procurement.

With respect to how much we invest in the space program, I would imagine that members of the Committee probably share my frustration that surveys show the public vastly overestimates NASA's budget, yet this is somewhat understandable given the high profile of our space missions. But I was simply astounded when I read a recent Congressional Quarterly cover story on the space program in which the author wrote that NASA's budget "has hovered at around one percent of the total budget since the mid-1970s." If only that were to be the case. Alas, the reality is that today's NASA budget represents less than one-half of one percent of the budget. If NASA's budget were actually a mere one percent of the Federal budget this hearing would be almost unnecessary.

Today, I have focused my testimony on the value of the International Space Station. Of course a more richer understanding of NASA's contributions to our national imperatives must include a discussion of the agency's work to advance weather forecasting and understanding of our planet's dynamic climate, to warn of solar storms and spot potentially devastating Earth crossing asteroids, and to assist in natural disasters—with NASA satellite support for relief and recovery efforts following the Japanese earthquake and tsunami and Alabama tornadoes being recent examples.

It would also be worthwhile to discuss how NASA's science missions to Mars, like the upcoming Mars Science Laboratory, the ongoing Dawn mission to the asteroids Ceres and Vesta, and orbiting NASA observatories like the Keppler Space Telescope

and soon to be launched James Webb Space Telescope will advance our understanding of the solar system and universe and the profound search for evidence of life in and outside the solar system, thus benefiting our Nation's reputation as the pacesetter of scientific discovery.

And by all means, it's worth discussing how NASA contributes to economic growth through the thousands of jobs and hundreds of new industries created as a direct result of NASA innovation. To illustrate this point, when USA Today published a list of the "Top 25 Scientific Breakthroughs" that occurred in the newspaper's first 25 years, nine of them came from space and eight directly from NASA. Indeed, the term "spinoff" was invented to describe specific technologies developed by NASA for its missions that are transferred for commercial use or some other beneficial application. Thus far, NASA has documented more than 1,500 spinoff success stories related to health and medicine, transportation, public safety, consumer goods, environmental and agricultural resources, computer technology and industrial productivity.

There is one other aspect of spaceflight that was brought home to me in deep and sometimes very personal ways virtually every day I spent in orbit—and still now as I'm stuck on the ground. That is the effect of space exploration on the educational goals of our youth. Most of the people of this country—and of most other countries—especially the young people, see eventual access to space as part of their future, and maybe even as much a right as access to airlines and highways. It's not clear that many people have a realistic understanding of the challenges of maintaining and growing our presence in orbit, much less through the solar system, but the ultimate product of that interest is the benefit to our educational system, the motivation for students to excel in STEM subjects, and hopefully to help maintain our leadership in the world on many fronts. I know from speaking to schools around the globe, both from space, and on my feet, that the space program's influence on education is profound, but still not fully capitalized upon. As Administrator Bolden said, "Through the science, research, and technology demonstrations conducted on the National Lab [in space], we will build foundational knowledge, advance economic competitiveness, and prepare for the grand journeys ahead.

Finally, a discussion of NASA's contributions to national imperatives must include the subject of which nation will be first among nations in leading peaceful human and robotic exploration of the solar system while learning how to live and travel more safely and efficiently here on Earth. It is not a foregone conclusion that the United States will remain the preeminent spacefaring nation, and will reap the benefits of leading the march of progress beyond Low Earth Orbit. That is why I am gratified that this hearing is being held, and I am honored to sit alongside people who care deeply about our future in space.

In closing, I am proud that our Nation continues to inspire people throughout the world for our commitment to freedom, creativity, exploration, and commerce, and through our leadership in the frontier that will define the future of human civilization. I feel a special responsibility because of my unique position as the only American who was off the planet on September 11, 2001, to spread the word that our leadership in space is vital to our way of life and our future, is a hard won accomplishment, and one we should never consider surrendering easily. In space we inspire respect, and sometimes envy, but always we show we are leading. Our freedoms allow us to do that. This, to me is the abiding lesson of being in space on September 11.

Thank you for the opportunity to testify before this important hearing.

Senator NELSON. Thank you.

Mr. Pulham?

STATEMENT OF ELLIOT HOLOKAUAHI PULHAM, CHIEF EXECUTIVE OFFICER, THE SPACE FOUNDATION

Mr. PULHAM. Thanks, Senator.

Senator Nelson, members of the Committee, committee staff, I would like to thank you for your service to our nation. And I would like to thank you for the opportunity to offer testimony today on the impact and importance of U.S. space programs.

Space Foundation's mission is to advance space endeavors to inspire, enable, and propel humanity. Implicit in this mission is our understanding that the exploration, development, and use of space really does inspire our nation and the world, really does enable us

to dare greatly, achieve our goals, and propel us confidently into the future.

First, let me address the global space economy. The data I am citing today is from *The Space Report 2011*. I have a copy here, and I think most of the staff already have copies of this. It is our most recent annual report on the industry.

Over the past 6 years, the global space economy has grown by 48 percent, from $164 billion in 2004 to $276 billion in 2010. The average annual growth rate of the industry increased from about 5 percent to nearly 8 percent last year. That is one heck of a strong industry and a good investment.

The space economy comprises products and services in both terrestrial and space-based infrastructure. While government space activities continue to play a major role, the space economy today is predominantly commercial.

Commercial satellite services, commercial satellite infrastructure together accounted for $189 billion in 2010. That is nearly 70 percent of total space activity. Nonetheless, with civil and national security space programs totaling some $64.6 billion in 2010, the United States remains by far the largest government player.

Now space is a tremendous economic engine, as my colleagues have referred to. The space products and services have, indeed, become an integral part of daily life. Whether during work or leisure hours, most people reap the benefits of space systems and technology continuously and, as you said, Senator, without probably knowing it.

The degree to which U.S. national investments in space have proven to be high-impact investments of tremendous national benefit cannot be overstated. After all, today's robust commercial space industry has its origins in government space investment.

DirecTV, Sirius XM Satellite Radio, CNN, ESPN, Monday Night Football, and countless other satellite services are all the grandchildren of America's investment in the Telstar Program. Google Earth, satellite weather, commercial imagery from space, and countless related value-added applications are the descendents of the Corona Spy Satellite Program.

The U.S. aerospace industry, which, by some estimates, accounted for 50 percent of the new wealth generated in America between 1962 and 2002, built its muscle on Government space investments, like Dyna-Soar, X–15, Mercury, Gemini, Apollo, X–24A, M2–F3, HL–10, and the list goes on—Space Shuttle, International Space Station.

Uniquely, however, U.S. national investments in space have spawned new technologies and new industries that could not even have been imagined when those investments were made. Because spacecraft needed a renewable source of energy on orbit, today we have a photovoltaic solar power industry, renewable energy. Because spacecraft needed to be guided and controlled, today we have accelerometer technology used in everything from triggering seatbelts and airbags in our cars to orienting SmartPhones.

Because NASA needed to accurately dock and undock spacecraft, today we have precision-guidance technology that enables Lasik eye surgery. Because NASA needed to protect the environment at

Kennedy Space Center, today we have advanced environmental containment and cleanup technologies.

Because the Air Force required a precise global positioning system, today GPS is the fundamental underlying architecture for commerce, finance, logistics, inventory management, commercial, military, law enforcement, emergency services, and personal navigation around the world. And because NASA required unprecedented turbo pump capability to power the Space Shuttle main engines, today we have lifesaving heart pump technologies.

None of these outcomes were expected. These technologies and more than 40,000 others are the result of our previous focused national investments in space.

A third point I would like to touch upon is space and foreign policy and national security. The funding of national space programs has brought tremendous benefit to U.S. foreign policy and national security. Our leadership in space has been a preeminent factor in American soft power since the dawn of the space age.

While President Kennedy's speech at Rice University is often quoted for its inspirational values, less quoted are the political and national security realities that America was coming to grips with at that time. "Man," said Kennedy, "in his quest for knowledge and progress, is determined and cannot be deterred. The exploration of space will go ahead, whether we join in it or not. And no nation, which expects to be the leader of other nations, can expect to stay behind in this race for space."

Whether our objective is to win the cold war, as in Apollo; extend a hand in friendship, as in Apollo Soyuz; incentivize collaborative behavior, as in the Shuttle-MIR Program; or build a broad-based international community, as in the International Space Station Program; the soft power of space programs is often one of our best foreign relations and national security tools.

All Americans know about the successful mission to get Osama bin Laden. I wonder how many of us will ever know how huge a role space played in that accomplishment.

Finally, it must be recognized that our national intellectual capacity is directly affected by our investment in space programs. As the Apollo Program was gaining momentum, enrollment in graduate studies in science and engineering was also gaining momentum. In fact, the Apollo Program was both expected and intended to double the number of American scientists and engineers.

Doing the hard things requires our best and brightest minds. Developing this intellectual capacity requires inspiring, challenging, and exciting work to do. When America has made that investment, we have never failed to achieve our capacity for greatness.

Thank you.

[The prepared statement of Mr. Pulham follows:]

PREPARED STATEMENT OF ELLIOT HOLOKAUAHI PULHAM, CHIEF EXECUTIVE OFFICER, THE SPACE FOUNDATION

Senator Nelson, Members of the Committee, and Committee Staff, thank you for your service to our nation, and thank you for the opportunity to offer testimony on the impact and importance of U.S. space programs—both in meeting the needs of humanity, and achieving the strategic goals and objectives of the United States. The Space Foundation is a 501(c) 3 non-profit operating foundation, and our mission is "to advance space-related endeavors to inspire, enable and propel humanity." Im-

plicit in this mission is our understanding that the exploration, development and use of space really *does* inspire our Nation and the world, enable us to dare greatly and achieve our goals and propel us confidently into the future.

Growth of the Global Space Economy

First, the global space economy. The Space Foundation pursues our mission by educating and informing. The bedrock of our ability to do this is our commitment to providing accurate, fair, impartial and nonpartisan data and analysis. *The Space Report,* our annual publication on the global space economy, is the authoritative guide to global space activities. The data I am citing today is from our most recent report.

Over the past six years, the global space economy has grown by 48 percent—from $164 billion in 2004 to $276 billion in 2010. The average annual growth rate of the industry increased from about 5 percent to nearly 8 percent last year.

The space economy comprises products and services, and both terrestrial and space-based infrastructure. While government space activities continue to play a major role, the space economy is today predominantly commercial. Commercial satellite services and commercial satellite infrastructure together accounted for some $189 billion in 2010—nearly 70 percent of total space activity. In addition to being heavily commercial, space is very international. Of the 25 largest satellite communication companies in the world, only one is headquartered in the United States. Roughly three quarters of all commercial satellites are manufactured outside the U.S. Global space employment has been stable over the past couple of years, with job increases in Japan, India, Germany and other nations offsetting job losses in the United States. Nonetheless, with civil and national security space programs totaling some $64.67 billion in 2010, the United States remains by far the largest government player.

Space systems today form the essential infrastructure of modern life, providing everything from routine weather forecasts, driving directions, entertainment and telephone service to inventory tracking, resource management and telemedicine. There is increasing awareness of the value of space as an economic engine that is crucial to many other economic sectors.

In 2010, as the global economy continued to battle back from recession, the space industry not only maintained its growth, but actually gathered momentum. The commercial sector flourished, adding billions of dollars to the economy. The commercial sector has long been involved in national space programs, primarily as contractors and service providers. This role is expanding due to new government policies that encourage greater reliance on commercial providers, particularly in the United States. These policies provide opportunities that have generated significant interest among traditional aerospace companies, as well as newer space actors, as the commercial sector seeks resources to develop its technological capabilities.

Additionally, more countries are becoming involved in space or are revitalizing dormant space programs, with Australia, South Africa and Iran as recent examples. In many cases, these space actors are incorporating a deliberate commercial element in their space programs that targets economic development and technology creation.

The role of civil society in space activity is also evolving. The emergence of smallsats and cubesats is lowering costs and barriers to entry, offering civil actors new avenues to engage in space activity. When smallsats are networked, the opportunities for new science and commercial applications can grow exponentially. Commercial human spaceflight also opens an avenue for people to experience space on a personal level, and it furthers public interest in space activity even for those who do not leave the ground. The growing engagement of society in space pursuits not only stirs our imagination, but also brings us closer together—researchers, scientists, business professionals and government officials—to explore the practically limitless opportunities that space promises.

Space as an Economic Engine

Space products and services are an integral part of daily life, expanding each year into new areas of human activity. In one dramatic example, space technology and expertise helped to ensure the survival and rescue of a group of Chilean miners trapped underground. This experience was but a single instance of how the knowledge gained from human activity in the challenging environment of space can be applied to life on Earth. In more commonplace situations, new space applications are helping people communicate with each other and access entertainment as they travel by ground, sea or air. Satellite-enabled Internet connections are becoming commonplace as airlines outfit their fleets with the latest equipment. Navigation applications for cell phones can combine input from built-in cameras and GPS chips, enabling users to view directions as an overlay on an image of their surroundings.

GPS tracking systems installed on race cars allow people playing computer games to participate in virtual competitions against professional drivers during real racing events. Whether during work or leisure hours, most people reap the benefits of space systems and technology as an integral part of their daily lives.

The commercial sector continues to incorporate space technology both in its manufacturing processes and in its products. The glass manufacturing industry is incorporating techniques used in the analysis of data from the Hubble Space Telescope and the semiconductor industry is creating more powerful microchips using technology developed for building ESA's XMM–Newton X-ray observatory. Consumers can purchase clothing made from textiles originally developed for use by astronauts or have their hair styled with tools that smooth and soften hair using nano-ceramic technology developed by NASA. Not only does space contribute to the wealth of products available to consumers, it also enables companies to estimate consumer activity by observing the ebb and flow of customer traffic in the parking lots of retailers by means of satellite imagery.

On a more global scale, satellites offer a unique perspective that helps to explain the human relationship with the environment. From enabling forestry managers to track the spread of tree-destroying Rocky Mountain pine beetles to helping coordinate cleanup efforts after the Gulf of Mexico oil spill to monitoring the effects of the earthquake in Japan, satellite data is critical to managing natural resources and the response to manmade disasters. It is almost unthinkable now to consider the prospect of facing a natural disaster without the communications and imaging capabilities provided by space systems.

Individuals, companies and nations continue to create new space-related products and services, capitalizing on the intellectual and financial investments made in space technology. Many governments have realized the benefits of using space technology as a tool for carrying out their responsibilities and as a means of generating economic growth. These governments play an important role in developing new space technology, with methods such as financing commercial companies, transferring government technology to the commercial sector and creating a supportive regulatory regime.

Regardless of the exact measures undertaken, it is clear that governments recognize the need for further growth of space capabilities. Government space spending around the world increased to $87.12 billion in 2010. The U.S. government space budget, which accounted for 74 percent of worldwide governmental space spending, was flat at $64.63 billion. Numerous governments announced their intent to expand their national space programs in 2010, including Canada, Germany, Israel, Japan and India. As these policies translate into budgets and program activities, they will increase total government spending on space globally; to the extent that funding for U.S. Federal space programs remains flat, both inflation and increased spending by other nations will erode U.S. leadership.

The degree to which U.S. national investments in space have proven to be high-impact investments of tremendous national benefit cannot be overstated. After all, today's robust commercial space industry has its origins in government space investment. DirecTV, Sirius/XM radio, CNN, ESPN, Monday Night Football and countless other satellite services are all the grandchildren of America's Telstar program. Google Earth, satellite weather, commercial imagery from space and countless related, value-added applications are the descendants of the Corona spy satellite program. The U.S. aerospace industry, which by some estimates accounted for 50 percent of the new wealth generated in America between 1962 and 2002, built its muscle on government space programs like Dyna-Soar, X–15, Mercury, Gemini, Apollo, the X–24A, M2–F3, HL–10, the Space Shuttle and the International Space Station.

Uniquely, however, U.S. national investments in space have spawned new technologies and new industries that could not even have been imagined when those investments were made. The act of doing things "not because they are easy, but because they are hard"[1] leads to the creation of capabilities that have not previously existed; these, in turn, can lead to entirely new industries. Take, for example, the cordless tool industry. Prior to NASA having a requirement for cordless power tools on the Moon, the power tool industry was content to continue manufacturing longer and longer extension cords. The unique NASA requirement gave birth to a solution that no one had imagined; NASA contractor Martin Marietta hired Black & Decker, and the rest is history. Today cordless power tools are manufactured in Maryland,

[1] "We choose to go to the Moon in this decade and do the other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one which we intend to win."—John F. Kennedy, Rice University, September 12, 1962

North Carolina, South Carolina, Georgia, Mississippi, Tennessee, Arkansas and Texas—and increasingly in Japan, China and Europe.

This is a very important phenomenon to understand: that investing in research to support a specific desired outcome will generate solutions and technologies that otherwise would not develop.

Take the humble, modern microwave oven. Research directed at improving the common oven would likely have resulted in ovens that are better insulated, more energy efficient and so on. But such efforts would probably not have resulted in a microwave oven. The use of amplified microwaves, initially in a device called a Klystron, came not from the oven or appliance industry, but from a directed effort to develop defense radar.

This is the way that invention and discovery works, and this is why America's past investment in space programs has yielded such stupendous returns:

- Because spacecraft needed a renewable source of energy on orbit, today we have a solar power (photovoltaics) industry.
- Because spacecraft needed to be guided and controlled, today we have accelerometer technology used in everything from triggering automotive seatbelts and air bags to orienting smart phones.
- Because NASA needed to accurately dock and undock spacecraft, today we have precision guidance technology that enables LASIK eye surgery.
- Because NASA needed to protect the environment from toxic chemicals associated with rocket launching, today we have advanced environmental containment and clean-up technologies.
- Because the Air Force required a precise global positioning system, today GPS is the fundamental underlying architecture for commerce, finance, logistics, inventory management and commercial, military, law enforcement, emergency services and personal navigation around the world.
- Because NASA required unprecedented turbo-pump capability to power the Space Shuttle main engines, today we have life-saving heart pump technologies.

None of these outcomes were expected. These technologies, and more than 40,000 others, are the result of our previous national investments in space.

Space and Foreign Policy, National Security

The funding of national space programs has also brought tremendous benefit to U.S. foreign policy and national security, both directly, and indirectly.

U.S. leadership in space has been a leading contributor to American "soft power" since the dawn of the space age. The nation's entry into the space race is often seen only as a reaction to the Soviet Union's launch of Sputnik; the doctrine behind this reaction is worth remembering. Kennedy's speech at Rice is often quoted for its inspirational and humanistic value. Less often quoted are the political and national security realities that America was coming to grips with:

> ". . . man, in his quest for knowledge and progress, is determined and cannot be deterred. The exploration of space will go ahead, whether we join in it or not, and it is one of the great adventures of all time, and no nation which expects to be the leader of other nations can expect to stay behind in this race for space."[2]

The mastery of space has always carried with it the not-so-subtle message to friend and foe: This is what we are capable of. You want to work with us. You want to be our friend. You want to follow our lead. You do not want to challenge us.

The message of the Apollo program was very clear—the U.S. triumphs over the Soviet Union and democracy triumphs over communism. We win. We are the leader. Follow us.

Whether our objective is to win the Cold War (Apollo), extend a hand in friendship (Apollo-Soyuz), incentivize collaborative behavior (Shuttle-Mir) or build a broad-based international community (ISS), the soft power of space programs is often one of our best foreign relations and national security tools.

Certainly, space programs have also been inextricably linked with "hard" power. Our current expendable launch systems descend from ICBM boosters. The Space Shuttle was configured so that it could carry out clandestine military missions.

---

[2] Kennedy continues: "Yet the vows of this Nation can only be fulfilled if we in this Nation are first, and, therefore, we intend to be first. In short, our leadership in science and in industry, our hopes for peace and security, our obligations to ourselves as well as others, all require us to make this effort, to solve these mysteries, to solve them for the good of all men, and to become the world's leading space-faring nation."

Friendly American satellites that carry out environmental monitoring and commercial satellites that deliver exquisite images of earth from space have their origins in Department of Defense space programs. Indeed America's largest secret space program, for decades, was the National Reconnaissance Office.

The ability to observe other nations, share intelligence instantly around the world and, when necessary, to strike, are all dependent upon our investments in national space programs. All Americans know about the successful mission to get Osama Bin Laden. They should also know that CIA Director Leon Panetta specifically praised the National Geospatial-Intelligence Agency (NGA) and its role as providing the essential satellite imagery of Bin Laden's lair that enabled the raid to take place.

Space and Our National Intellectual Capacity

Finally, it must be recognized that our national intellectual capacity—the brain power we can bring to bear on any problem, issue or challenge—is directly affected by our investment in national space programs. As the Apollo program was gaining momentum, enrollment in graduate studies in science and engineering was also gaining momentum. In fact, and again citing Kennedy's speech at Rice, the Apollo program was expected and *intended* to double the number of American scientists and engineers[3].

Doing the hard things requires our best and brightest minds. Developing this intellectual capacity requires inspiring, challenging, and exciting work to do. When America has made that investment, we have never failed to achieve our capacity for greatness.

Senator NELSON. Mr. Slazer?

STATEMENT OF FRANK SLAZER, VICE PRESIDENT, SPACE, AEROSPACE INDUSTRIES ASSOCIATION

Mr. SLAZER. Thank you, Chairman Nelson and Ranking Member Boozman and the distinguished members of the Subcommittee.

It is both an honor and a pleasure to be able to testify before you here today on the importance of NASA's space exploration program and the role of space in addressing America's national priorities.

I am here on behalf of the Aerospace Industries Association, an association of over 300 aerospace companies representing over 90 percent of the U.S. industry. Our industry sustains nearly 11 million jobs nationwide, including many high-skilled, high-technology positions.

Our organization was disappointed that the President's Fiscal Year 2012 budget proposes to underfund NASA by nearly $800 million below the $19.4 billion authorized level, a level agreed upon just last fall. Given the current fiscal environment, however, AIA believes the level of NASA funding proposed by the President, $18.7 billion, is the minimum required for its programs.

When allocating this funding, AIA's position is that the funding distribution should reflect the budget priorities as outlined in the Fiscal Year 2010 NASA Authorization Act.

Despite the clear bipartisan direction provided in the 2010 Authorization Act and the 2011 year-end continuing resolution, substantial uncertainty remains over the direction NASA will take, most specifically on the new heavy lift space launch system. The impact of the long-delayed CR, the current budget climate, and the impending gap in America's ability to launch crews into space are

[3] "Despite the striking fact that most of the scientists that the world has ever known are alive and working today, despite the fact that this Nation's own scientific manpower is doubling every 12 years in a rate of growth more than three times that of our population as a whole, despite that, the vast stretches of the unknown and the unanswered and the unfinished still far outstrip our collective comprehension. . . . During the next 5 years the National Aeronautics and Space Administration expects to double the number of scientists and engineers in this area."

causing ripple effects throughout the space industrial base and its highly trained workforce.

Now that the Space Shuttle is being retired and the U.S. is paying Russia over $60 million a seat to get crew to the International Space Station, it is critical that NASA's exploration and crew transportation programs be adequately funded to remain on track.

Two generations of Americans have never known a time when our nation was not engaged in human spaceflight. But let us be clear. This is a legacy, not an entitlement. Without continued investment, this could become the last generation of Americans to be part of a space-faring society.

The on-again, off-again plans for Shuttle's replacement over the past decade have led to considerable workforce uncertainty across the entire industrial base, where firms are faced with wrenching decisions to let highly skilled personnel go due to lack of funding and/or clear direction. In addition to workforce impacts, fluctuating budgets and delays take their toll on schedule, production capability, and industry's ability to manage programs, sending mixed signals to industry and placing these complex space programs at risk of overruns or cancellation and jeopardizing the prior taxpayer investments.

Interruptions or cancellations negatively impact large companies and can be catastrophic to smaller firms, often the only entities with unique abilities to produce small, but critical components on which huge portions of our economy, infrastructure, and national security depend.

As an example, only one firm in the United States produces a chemical called ammonium perchlorate, which is necessary for solid rocket propulsion. It is used in the Space Shuttle solid rocket motors, other space launchers, and a wide variety of military systems. The Shuttle's retirement is already impacting a wide range of users, as costs rise due to this smaller business base.

Whenever government budgets are cut significantly, U.S. space industrial capability shrinks. This capacity loss could potential leave the industry incapable of building civil or national security space systems in the future.

Developing the aerospace workforce of the future is a top issue for our industry. NASA's space programs remain an excellent source of inspiration for our youth to study the STEM disciplines—science, technology, engineering, and mathematics—and to enter the aerospace workforce.

AIA is committed to STEM education and, just last weekend, hosted over 600 students from all across the country at a rocket-launching competition, the Team America Rocket Challenge—TARC—in Virginia. While the students there are clearly motivated, for many students, the lack of program continuity is impacting the attractiveness of the aerospace professions.

For example, in 2009, a survey was done where 60 percent of students in STEM curricula in colleges found the aerospace industry to be an unattractive place to work. One of the reasons for lack of interest in aerospace may be the uncertainty of NASA programs.

Just as the recent Wall Street crisis turned young people away from financial careers, uncertainty and a lack of job security in aerospace also hurts recruitment. A commitment to a robust

human space flight program will help attract students to STEM degree programs and hold on to the current workforce, while also benefiting national security space programs, many of which, while very exciting, are classified.

A robust and sustainable space exploration program is essential to building our future economy. AIA believes that a fundamental driver of economic growth since the 1960s has been our Nation's investments in space-driven technology and inspiration. In fact, today, a number of new commercial space systems are being developed by entrepreneurs who have made their fortunes in information technology or other fields, but whose intellectual development was inspired during the Apollo era.

In conclusion, the U.S. space program is at a critical juncture. While cutting the Federal deficit is essential for our economic future, cutting back on space investments is a penny-wise, but pound-foolish approach that would have an infinitesimal impact on the deficit, even as emerging world powers are growing their space capabilities.

Instead of the embarrassing situation of buying crew launches from Russia 50 years after our first manned space flight, our nation's future will hopefully include one or more commercially developed American crew vehicles supporting the International Space Station and possibly new commercial space stations, along with a robust NASA multipurpose crew exploration vehicle and a heavy lift launch system for missions of exploration beyond Earth orbit. But this bright and inspiring future is dependent on our nation continuing to make the investments necessary to lead in space.

I thank the Committee for their time, and I would be happy to answer any questions.

[The prepared statement of Mr. Slazer follows:]

PREPARED STATEMENT OF FRANK SLAZER, VICE PRESIDENT, SPACE, AEROSPACE INDUSTRIES ASSOCIATION

Introduction

Chairman Nelson, Ranking Member Boozman, distinguished members of the Subcommittee. It is an honor and a pleasure to testify before you today on the importance of NASA's space exploration program and the role of space in addressing America's national priorities.

I am here on behalf of the Aerospace Industries Association (AIA)—an Association of over 300 aerospace manufacturing companies and the highly-skilled employees who make the spacecraft, launch vehicles, sensors and ground support systems employed by the National Aeronautics and Space Administration (NASA), Department of Defense, National Oceanic and Atmospheric Administration (NOAA), the National Reconnaissance Office (NRO), and other civil, military and intelligence space organizations. This industry sustains nearly 11 million jobs, including many high-skilled, high-technology positions. The U.S. aerospace manufacturing industry remains the single largest contributor to the Nation's balance of trade, exporting $80.5 billion and importing $27.2 billion in relevant products in 2010, for a net surplus of $53.3 billion.[1]

We appreciate the efforts of Congress to keep our commercial, civil and national security space programs healthy. We are pleased that Congress recognizes that space capabilities have increasingly become part of everyday life and that virtually every part of the U.S. economy has been touched by their applications.

Space programs are essential to our national, technological and economic security. U.S.-developed space technology and its many spin-offs have fueled our economy and made us the unquestioned technological leader in the world for two generations.

[1] U.S. Census Bureau, Merchandise Trade Exports/Imports Quarterly 2010.

U.S. economic and technological leadership enabled us to prevail in the Cold War and emerge as the world leader in a new era.

AIA was disappointed that the president's Fiscal Year 2012 budget proposal underfunds NASA by nearly $800 million below its authorized level—$19.4 billion—agreed upon just last fall. Given the current fiscal environment, AIA believes that the level of funding proposed by the administration for NASA provides at least the minimum required for its important programs. It is therefore imperative that NASA receive the full amount of the president's Fiscal Year 2012 budget request of $18.7 billion. When allocating this funding, AIA's position is that funding for NASA should reflect the budget priorities as outlined in the NASA Authorization Act of 2010 as closely as possible.

The Need for Program Stability

Despite the clear bipartisan direction provided in the NASA Authorization Act of 2010 and in the Fiscal Year 2011 Continuing Resolution (CR), substantial uncertainty remains over the direction NASA will take—most specifically on the new heavy-lift space launch system. The impact of the long delayed Fiscal Year 2011 CR, the current budget climate and the impending gap in America's ability to launch crews into space—after decades of ever increasing capability—are causing ripple effects throughout the space industrial base and highly trained space workforce in both private and public sectors.

Fluctuating budgets and delayed programs take their toll on schedule, production and maintaining a skilled workforce—exacerbated by the winding down of the space shuttle program. This funding and programmatic instability may result in the permanent loss of this highly skilled, unique human capital by reducing the options for retaining this specially trained and skilled workforce. Our nation's aerospace workforce is a perishable national treasure; experienced aerospace talent, once lost, may be unrecoverable and new workers without this critical experience may take years to train. Unfortunately, the on-again off-again plans for the Shuttle's replacement over the past decade have led to considerable uncertainty not only at NASA—where civil service positions are protected—but across the entire industrial base where firms are faced with wrenching decisions to let highly skilled personnel go because of the lack of clear direction.

At a time when the space shuttle is being retired and the United States is paying Russia over $60 million a seat to get crews to the International Space Station, it is critical that NASA's new programs for exploration and crew transportation be adequately funded to remain on track. Fifty years after astronaut Alan Shepard became America's first man in space, two generations of Americans have never known a time when we were not engaged in human space flight. But let us be clear, this is a legacy not an entitlement—without continued investment, this could become the last generation of Americans being members of a space faring society. In addition to workforce impacts, failure to stick to a space program funding plan makes it difficult to manage them effectively; sends mixed signals to an industry making long term investments; and places these programs at risk of overruns or cancelation—jeopardizing the investments already made by taxpayers.

NASA's research and development efforts have consistently produced groundbreaking technologies with benefits for nearly everyone on the planet. Investments made in NASA have produced invaluable benefits to our national security, economic prosperity and national prestige and should be pursued as sound economic stimulus.

NASA Space Investment Benefits All Sectors, Including National Security

The U.S. military and national security communities rely on the space industrial base to provide them with capabilities required to keep our Nation secure. Our space industrial base designs, develops, produces and supports our spacecraft, satellites, launch systems and supporting infrastructure. These systems are often produced in small or even single numbers. We need to keep this base healthy to maintain our competitive edge.

Interruptions or cancellations negatively impact large companies and can be catastrophic to smaller firms—often the only entities with the unique abilities to produce small but critical components on which huge portions of our economy, infrastructure and security depend. As an example, only one firm in the United States produces ammonium perchlorate—a chemical used in solid rocket propellants including the space shuttle solid rocket motors, other space launchers and military applications. Retiring the shuttle will impact all these other users as costs rise due to a smaller business base.

The U.S. military and national security communities rely on the space industrial base to provide them with capabilities they require to keep our Nation secure. Due to export restrictions on space technology and limited commercial markets for space

systems, key elements within industry often must depend on stable government programs for survival. This two-way, symbiotic relationship means that in order to keep our overall national security strong, both sides of this relationship are critical.

Given the lack of a large external space market, such as exists in civil aviation, if government spending pulls back from investing in the space domain—be it in NASA, the Defense Department or Intelligence Community—the industrial base will shrink accordingly. This will mean capacity loss and potentially leaves the United States incapable of building certain national security assets in the future.

Investing in NASA Benefits STEM Education

Developing the aerospace workforce of the future is a top issue for our industry. NASA's space programs remain an excellent source of inspiration for our youth to study the STEM disciplines—science, technology, engineering and math—and to enter the aerospace workforce. In fact, the exciting periods of our space program history are reflected in the demographics of our industry and the influx of young workers they engendered.

Unfortunately, the state of education for our young people is today in peril, including poor preparation for STEM disciplines. American students today rank 25th in math and 17th in science internationally. Low graduation rates of students in those fields and an overall lack of interest in STEM education contribute to a looming shortage of workers qualified to become professionals in our high tech industries.

A recent study, Raytheon found that most middle school students would rather do one of the following instead of their math homework: clean their room, eat their vegetables, go to the dentist or even take out the garbage. This lack of interest extends into interest in aerospace. For example, in a 2009 survey 60 percent of students majoring in STEM disciplines found the aerospace and defense industry an unattractive place to work.[2]

One of the reasons for the lack of interest in aerospace and defense could be the uncertainty of NASA programs.[3] Just as the recent Wall Street crisis turned young people away from financial careers, lack of job security in aerospace will hurt recruiting efforts. The video gaming industry has captured the magic to attract young people, while space—despite its history and potential—has lagged behind. In some instances, our own employees discourage their children from pursuing careers in aerospace engineering due to the uncertainty of future programs and career prospects. A commitment to a robust human spaceflight program will help attract students to STEM degree programs and help retain the current workforce—which also benefits national security space programs, many of which are not in the open.

While AIA and NASA are vigorously engaged in the "supply" side of the equation—exciting and inspiring students to study math, science and engineering—it's the "demand" side that needs Congressional action by providing the resources needed for visible and inspiring aerospace projects. These, in turn, provide young people with exciting programs to work on in the near future and on an ongoing basis. A robust and sustainable space exploration program is essential to building a future aerospace workforce capable of technological innovation and economic competitiveness.

Investments in NASA Have Increased Economic Prosperity

Since its beginnings, NASA has been at the forefront in developing new technologies to meet the challenges of space exploration and much of what has been developed has had benefits in other areas. The list of NASA-derived innovations is impressive and wide-ranging, including memory foam cushions, video image stabilization technology, cordless power tools, power sources for heart defibrillators, ventricular assist pumps for heart disease, portable breathing systems for firefighters and many others. These NASA-enabled innovations are not just old history; for example, today the International Space Station is enabling us to develop new vaccines to protect people from Salmonella and MRSA pathogens by exploiting the organism's response to the weightless environment.

Past NASA investments such as the Apollo moon landing program stimulated technology development like the miniaturization of electronic circuits. Electronic computers were first created during World War II, but miniaturization in the 1960s enabled the first personal computers to be created in the late 1970s and early 1980s—by a generation of inventors who grew up during the Apollo era. In fact, today a number of new commercial space systems are being developed by entre-

[2] 2009 Experience Industry Survey.
[3] 2007 National Academies: Building a Better NASA Workforce.

preneurs who have made their fortunes in information technology or other fields, but whose intellectual development was inspired during Apollo.

NASA is a Source of National Pride

And then there are space program benefits that don't have a dollar figure attached—those unquantifiable "know it when you see it" benefits that reap long-term rewards—increasing our Nation's pride in our abilities and garnering attention from across the globe. These include the already mentioned Apollo program, the space shuttle and International Space Station, numerous planetary spacecraft which have revealed the wonders of our solar system as well as spacecraft which have helped us understand our home planet and the universe. If there is one area where the world unquestionably looks to the U.S. for leadership, it is in our space program.

Conclusion

The future of U.S. space investments are threatened due to our constrained fiscal environment. While cutting the Federal deficit is essential to assuring our economic future, cutting back on exploration investments is a penny-wise but pound-foolish approach that will have an infinitesimal impact on the budget deficit. Cutting exploration further threatens our economic growth potential and risks our continued national technical leadership overall—even as emerging world powers increase their investments in this important arena. China, India, South Korea and other rapidly developing economies are investing in space technology.

In the decade ahead, our Nation's future in space will likely see one or more commercially developed American crew vehicles supporting the International Space Station and potentially new commercial space stations, as well as a robust NASA multipurpose crew exploration vehicle and new heavy lift launch system that will be getting ready for new missions of exploration beyond Earth orbit. But this bright and inspiring future is dependent on our Nation continuing to make the critical investments in programs and technologies needed to lead in space.

In conclusion, the United States human spaceflight program is at a critical juncture. As a nation we can choose to continue our leadership in manned exploration and innovation or inevitably fall behind.

I thank the Committee for their time and would be happy to answer any questions.

Senator NELSON. And all of your written statements will be put in and made a part of the record.

I would like to start with you, Dr. Chyba. I am just going to ask one question, and then I am going to flip it to you, Senator Hutchison.

Dr. Chyba, you participated on the Augustine Commission, and one of their recommendations was the Flexible Path, which informed a great deal of the authorization bill that Senator Hutchison and I worked on. So how would you respond to the criticisms over the incremental approach or headlines that come out about a rocket to nowhere?

Dr. CHYBA. Thank you, Senator. I appreciate that question.

As you know, the Augustine Committee made—presented a set of possible options. It didn't make recommendations among those options.

But the Flexible Path was one of those options. And if you look at our analysis, as I am sure you have, sir, of the different possible options according to the metrics against which we evaluated them, Flexible Path contained the other options. It ranked best in virtually—along virtually every metric. So I am not surprised that, in the end, it was the option that was chosen.

It also had the great advantage—or has the great advantage of providing the best budget profile. If you imagine a scenario in which you are going back to the Moon quickly, you not only have to develop the heavy launch vehicle, but you have to develop the landers. And the Constellation Program, that was a very capable,

a very capable lander, the Altair lander. With the Flexible Path, you do not have to up front develop all the lander infrastructure along with the heavy lift vehicle.

But the path, I think if it is not framed well, it is easy to level the criticism you just mentioned. But I think that, in the end, we have to think more carefully about what our future beyond low-Earth orbit looks like.

I said in my brief comments that everyone looks back on the Apollo Program with admiration. But we also need to draw lessons not only from that program, but from the 40 subsequent years of human space flight.

Twice since Apollo, there have been efforts made by U.S. Presidents to launch an Apollo-like initiative. George H.W. Bush—President George H.W. Bush announced his Space Exploration Initiative, but the budget wasn't there. That was an initiative to go to Mars. President George W. Bush had his vision for space exploration, which led to Constellation. Virtually immediately, the budget was below that to which Constellation was planning.

They had been planning—they were planning against an ultimate steady state of $10 billion a year. That was lower virtually instantly, as well as not taking into account the costs of de-orbiting station, which they were going to have to do in 2016. And ultimately, with the President's—President Obama's budget, we were looking at something closer to $7 billion a year.

So I think we have learned from experience that that kind of Apollo vision, as desirable and inspiring as it is, is not working for us as a vision for the future for NASA. So we need a different approach.

And I think the right approach is an approach in which we still keep our eye on the human move out into the solar system, on that inspiring vision. I want to get there as badly as anybody else. But we are not going to do it—our experience says we are not going to do it by announcing an Apollo-like program.

What we have to do instead I think is twofold. We have to develop a kind of infrastructure—or you might even call it an "ecosystem"—in low-Earth orbit that has a variety of ways of encouraging the advance of human space flight and cost-cutting in human space flight. And that includes encouraging this robust commercial sector.

But in order to do that, the government is going to have to provide demand-pull, where it is going to have to provide the station as a destination. And not for make-work, but for important experiments and developments that will further enable human space flight.

And also, let us hope—let us hope—this remains to be demonstrated, but let us hope there will turn out to be a commercial market, both with respect to suborbital flights and perhaps also with an additional private station-like inflatable entity that people want to go to. That remains to be seen. But I think that the government demand-pull alone is probably sufficient to get that ball rolling.

But simultaneously, because the commercial sector independently is not there yet, we have to have the heavy launch vehicle capability that is going to allow us to move out beyond low-Earth

orbit. So I favor, I absolutely support the authorization bill's approach to this.

This is not—Flexible Path is not a mission to nowhere. It is a mission to expand human civilization into our solar system, the most ambitious possible space objective. But it tries to do it in a way that I think has the hope of being sustainable, of actually providing us with that future.

If you look back at some of the reports that have been issued in the last 40 years about our future in space, too many of them, in my view, included dramatic artist's renderings of what our future was going to look like, with rocket ships flying everywhere and astronauts in backpacks going in every possible direction. I respect and admire that vision, but I think that our citizens and our children need more than PowerPoint depictions of what that future looks like, and I think Flexible Path is our best hope of obtaining that future.

Senator NELSON. Thank you, Dr. Chyba.

Senator Hutchison?

Senator HUTCHISON. Well, thank you, Mr. Chairman.

And I appreciate that very much because we tried to make the balance right within our budget constraints of a flexible way forward that does support private innovation, but also keeps the base of our expertise and what has already been proven also as an ongoing effort. And we hope we got the balance right.

But here we are. The Chairman and I and Senator Boozman are all very concerned about the delays, the indecision, the seeming unmotivated approach to modifying contracts so that you keep the industrial base. From 14,000 contractors and civil servants that have been in the Space Shuttle workforce, we are now down to about 7,000.

So we have cut our expertise and workforce in half, but what we were trying to do in the authorization bill was create a new vehicle where these people could be transferred and keep their expertise rather than have them leave and not be able to get them back.

I would ask Dr. Chyba, Mr. Slazer, and either of you as well—maybe, Captain, you as well—what can we do to motivate real movement and decisiveness in NASA that does keep the basic workforce for the goals that we all have? Because we share everything that you have said today, and yet have the private sector continue to innovate, but to keep the balance that we have tried to create and see some success?

I would just ask any of you who would want to step up to the plate. Because we are getting fairly frustrated.

Mr. SLAZER. Yes. I don't have a good answer for what the right technical solution is for NASA's launch vehicle. They are working that with a lot of people in industry, and they have undoubtedly got several workable options to proceed with.

But one thing I will give you from my experience watching the Space Station Program in the 1990s was that after it was redesigned for the umpteenth time, after about a decade of winning by one vote on the floor of the House to keep the program alive, it was decided to fund the Space Station at a fixed level of about $2 billion a year from about 1993, the early part of the Clinton administration. And it pretty much kept to that development funding level.

And by keeping to that level, although development programs really want to look like a bell curve, they don't—you know, optimally, you do them most efficiently like a bell curve. But if you know what your funding is going to be and if an effort is made by the White House and by Congress to protect that flat-line budget to allow them—protect a budget to allow them to manage to it effectively, we have this remarkable asset that is in space today.

And here it is less than 6 months after the authorization, and the President's request did not reflect the authorization. And then, on top of that, the Shuttle pension came in as a one-time expense. Well, we had a one-time expense prior to this, back in the 1990s—actually, back in the 1980s, after the Challenger was lost, where we made a one-time appropriation to cover funding the Endeavour. And that came in under budget, and the rest of NASA's program was not disrupted at the time.

If you throw disruptions into the funding plan, it makes it more difficult for NASA. It makes it more difficult for industry, and it makes it longer and more frustrating at the end to get a program.

So I don't know what the right answer is, as far as the NASA program. I know you have got a letter you have sent to NASA to try to figure it out, what their response is on that. But I will tell you that once a plan is agreed upon, sticking to that funding profile is the most important thing you can do for them and for industry.

Senator HUTCHISON. Do you think that we still have the expertise in the employees that are left? There's been another round of lay-off notices following when the Shuttle shuts down, do we have enough to fulfill the NASA part of the mission, or are we just getting bled to death so that all we will have is the private sector?

Mr. SLAZER. I guess my observation would be that many of the people that are being let go now are on the operations side, who are very expert at operating the Space Shuttle system. While we certainly need to have operational capabilities for new systems, one of the critical things—and it is the small tip of the spear, if you will—are the design engineers and scientists that can actually develop new systems.

And I think on that level, we may be doing pretty good because, right now, we have got at least three different commercial cruise systems being developed. We have got the Orion multipurpose crew exploration vehicle, and there are a number of activities still tied to Constellation relative to the launch vehicle that are going, as well as the upgrades being made to the EELV Program.

So I wouldn't say we are super healthy right now, but with the program we have got going now, at least that pointy end of the spear is there. But we need to figure out that transition of workforce because operational expertise is important as well. You need to be able to run these systems.

Senator HUTCHISON. Well, we have one more Shuttle. Is there anyone that is concerned—who is concerned about whether we still have the capability to do the last Shuttle, which is our cleanup Shuttle, to make sure we have everything on the Space Station that a Shuttle can take? Because when we go to Soyuz, we will not have much capability to take things to the station.

Captain Culbertson: Senator, I think I can address most of your question. I am pretty close still to the people at KSC, JSC, the

other NASA centers, and talk to them frequently about how things are going and what is happening with the missions and the countdowns, et cetera.

Your first question was, do we still have the expertise within NASA to safely conduct the missions? And my answer is yes. There are a lot of really, really good people still there.

It is unfortunate that people are being laid off. And it is not just in the government workforce. In fact, the major hit is to the contractor workforce. But these are people who have also been in the program for decades, who have the same corporate knowledge and expertise as what we attribute to NASA as a whole, and they are basically the arms and legs, and in many cases the brains, of what goes on.

So that is an issue, and it is a concern. It is one that we have seen coming for a while, and hopefully, people have done the best planning they could, both on a personal and professional basis, to prepare for these changes.

But the remainder of the workforce on both the government and industry side that I see is still extremely competent, still capable of leading, still capable of making the right decisions, and conducting operations safely, as well as moving out on the programs that are currently in the authorization bill. I believe that we have the people on both sides of the table to execute what has been asked of the country.

We do need to continue to have bipartisan support on that. One of the problems has been the continuous debate over what many would see as partisan issues over exactly what the details of NASA's direction should be. And I think we need to get that behind us and decide that we now have a plan that can be executed and that people need to move rapidly on it.

It will be a mix of commercial endeavors and government-led endeavors and I think we will need that going forward.

We need to continue to focus on the technological capabilities of the plans and teams that are working on them. And the business cases and business experiments that might be out there, we need to be cautious about. But by the same token, we need to encourage access to space by many, many people and many, many companies.

As I said before, the measure of whether we are remaining a great nation or not is whether we can get through this difficult time and maintain our leadership in space. It is going to require some hard decisions, and it is going to require commitment, bipartisan commitment from both the Congress and the government leadership.

Senator HUTCHISON. I think when you are referring to bipartisan, the Congress is speaking very forcefully of one mind, bipartisan. However, Congress and the administration, I think, is what you are referring to as not being in sync, which is clear.

Captain CULBERTSON. I am just a witness.

[Laughter.]

Senator HUTCHISON. Well, I think when you said——

Captain CULBERTSON. Yes, ma'am.

Senator HUTCHISON.—what we need is bipartisan, a bipartisan effort, we had one.

Captain CULBERTSON. Yes.

Senator HUTCHISON. We passed an authorization bill overwhelmingly.

Captain CULBERTSON. Well, and this committee particularly was a leader in doing it in a bipartisan fashion. And I think the whole government needs to take a lesson from that.

Senator HUTCHISON. I agree with you. Thank you.

Mr. PULHAM. Senator, if I may, I share your frustration in this regard. Whether you support the Flexible Path or not, the fact is that we have an authorization. That authorization sets out where we are going and what level of funding there is going to be for each component of where we are going.

And NASA has not always had that. They have not always had an authorization bill. And the Congress has taken great pains to set forth what is now law that says this is what NASA should do.

And I am just astounded that someone from NASA isn't sleeping on a couch in each of your offices and working this on a daily basis. Because it gives NASA the opportunity to get the enterprise focused around what the law of the land says will be done.

So I think the letter that you have sent to the Administrator is a good step. I think some additional meetings are clearly called for to make sure that the agency is implementing what they have given to implement.

Senator HUTCHISON. Thank you.

Dr. Chyba?

Dr. CHYBA. Senator, if I may, I will make one specific comment that is not as broad-reaching as my colleagues' comments. The Subcommittee has just been given a commercial market assessment from NASA that was requested in the 2010 authorization bill. There is a one-page appendix, Appendix B, in that market assessment that I would suggest would prove very useful to examine in greater detail.

And that is an appendix in which the agency looks at the—does a cost evaluation of the Falcon 9 spacecraft. And they cost out how expensive it would have been for NASA to have built that rocket. And with two different assumptions, they get an answer of $1.7 billion at the low end and $4 billion at the high end. They also state that they examined SpaceX's costing of it and have confirmed it, and it cost SpaceX $400 million.

So that, to me, suggests two things. One is that—well, if that is real, if that difference is real, that is encouraging about the future. And it would be good to learn as much as one can from that for how to do things differently in the future. It may mean that, ultimately, though not in the near term, the commercial sector could play a much more ambitious role.

But the other thing that I think one would want to understand in some detail would be why would it have been that much more expensive, somewhere between 4 and 10 times more expensive for NASA to do this? Especially at a time when the claim is that—when the statement is that—one of the issues facing NASA right now is how to develop the heavy launch vehicle within the budget profile that the Committee has given it?

I would hope that that kind of examination could be done in a cooperative way. You know, let us roll up our sleeves together and figure out what changes we might make. Because there is an impli-

cation there that there is a much less expensive way of doing things. Perhaps that will evaporate under closer examination, but certainly, one would want to understand that.

Senator HUTCHISON. Well——

Mr. PULHAM. I would like to associate myself with my colleague's remarks, and I would like to further suggest that the government has not always been terrific at estimating markets.

And I say that from the point of view of somebody who worked on the EELV Program in the early years. And it is pretty astounding how bad the estimates were for what was eventually going to happen with EELV.

So I would encourage the Committee to look toward a disinterested party, whether that be the GAO or an outside organization, to get an objective view on these costs.

Mr. SLAZER. As someone who also worked on EELV, I just have to intercede. The industry was also part of that market mis-estimation at the time. But EELV itself, although it has not met its cost objectives as well as had been hoped, was pretty amazing if you look at it from the perspective of how the government managed that program.

Between the two companies—and most of the money that went into the development work was money put in by Lockheed Martin or Boeing—less than $5 billion was invested. We wound up with two families of launch vehicles, brand-new LOX hydrogen main stage engine, the first one that had been built since the Shuttle main engine back in the 1970s.

We wound with a brand-new rocket factory. We wound up with two new pads—actually, three new pads and a capability that has not had a failure yet.

So if you want to look at how programs can be managed with government involvement, but still produce tremendous results affordably, EELV does have some lessons, I think, out there.

Senator HUTCHISON. Well, I think that your points are well taken. And I think there is a future in the private sector, which is why we have created the balance in our bill. But we also have to have the reliability, the backup systems, and all of the extra efforts that must be made when you are talking about human space flight.

And so, I think going at a measured pace is what we ought to be doing and assuring that we are not going to be moving so fast that we end up not having something that is reliable. And also, that we have all of the safety and backup systems that would be required.

And that we don't have big cost overruns that end up being more expensive in the long run because you are at a place where you don't have backups. You don't have anything that is an alternative. And something doesn't work in the one you have, and it was even mentioned within NASA that, oh, you know, we will put it all into the private sector, and then we will bail it out when we need to. Well, that is not a good business model either.

So I think the balance that we struck is what we would hope would be a measured and safe way forward, and also one that could produce the—I mean, if it really is a difference of $400 mil-

lion versus even $1.5 billion, then that is what we ought to be looking for.

Thank you.

Senator NELSON. Thank you, Senator.

And the authorization—just to build on your comments, the authorization bill requires NASA to look for these types of efficiencies that we have been talking here—better acquisition, better contracting—with an eye to bringing down the costs.

Senator Boozman?

Senator BOOZMAN. Thank you, Mr. Chairman.

Mr. Pulham, you mentioned in the opening of your testimony a number of measures, a number of goals. I think one of those was to inspire the world. You might elaborate on that again.

But also I would like for you to comment in regard to how we are doing as a nation, right now, in regard to those things, which I think we all agree are very important.

Mr. PULHAM. Well, thank you, Senator.

The three key words in our mission statement are "inspire, enable, and propel." And the inspiration part is a lot easier to do when you have a visible, vibrant program, as opposed to when you really don't know what is coming next.

If you have that program, that then enables a lot of things to happen. It enables the technologies to evolve. It enables people to create programs that engage students and teachers. It enables all Americans to see what is going on, take some pride in it, and be supportive of whatever amount of money we are putting into the program. And as my colleagues have noted, it is consistently Americans think we are putting an awful lot more into this endeavor than we have.

And then the third thing is to propel. You want to propel our nation in terms of its global leadership. You want to propel our scientific base, our engineering base. You want to propel our young people into programs in college that are hard programs, and to get them there without requiring mathematical remediation and to maintain that intellectual base and that intellectual capital that I talked about.

And I am not sure if that quite answers your question, but I really think it is terribly important that we have a vibrant space program. The International Space Station, as Frank knows, is very near and dear to my heart. I worked on that program when I was with Boeing down in Huntsville, Alabama. And the fact that there is not more known—that it is not more known that that program is up and running and that there is a tremendous amount going on there is detrimental in terms of our being able to support other space programs as a country.

I think if people don't get it that there is something wonderful that has happened from this, they have a hard time believing that something else wonderful is going to happen. And so, really leveraging that International Space Station is important.

I will say that at the level of teachers and students—and we have an academic branch to our organization—they do get the whole International Space Station thing once you start talking with them. If they come off the street into your classroom, they may not

have any knowledge of it whatsoever. But when you start working with them, they latch onto it. They build programs around it.

We have taken over a failing inner-city school and turned it into an aerospace academy, and the kids in that school use the latest aerospace software to track satellites, calculate when the International Space Station is coming overhead. And I guess my worry is that however we implement this Flexible Path, we do it in a way that people can see that something exciting is coming.

Senator BOOZMAN. Thank you very much, and I agree totally.

Dr. Chyba, I know you worked very hard on the commission, and you guys did a good job and explored a lot of different pros and cons in coming up with your decision. And you have alluded to this, but for the record, would you agree that an important element of any heavy lift vehicle and crew module would be the degree to which they maximize the use of previous investments in vehicle developments, propulsion systems, and infrastructure?

Dr. CHYBA. Thank you, Senator.

I should make a distinction between the Committee's work and my own view in that respect. As you know, the Committee simply presented options. So while it certainly factored into its analysis of different options as an explicit one of its metrics, that type of question that might have been called sustainability, but I might be misremembering the name, there was an explicit metric that looked at—well, there was a workforce metric, for example. The committee presented options. It didn't make recommendations.

My own view is that especially given that we are in this delicate position now of trying to move toward an expansion into the solar system, while we have to simultaneously maintain and foster this largely commercially driven, filling in behind NASA's spearhead, I don't think we have much choice currently but to build as much as possible on existing capabilities. There may be a price to that.

In the long run, that could mean that we have a system that costs less up front to develop but has higher recurring costs in the future. I hope that the way to mitigate that—that there would be a way to mitigate that, which would be to make the system as evolvable as possible. I think you already see that in the way that the use of the Shuttle main engines are being discussed for that heavy lift vehicle, that they will be moved toward a kind of disposable version of the Shuttle engines that would be less expensive.

So as long as that system is evolvable, so that there is at least a prayer of bringing down recurring costs, I think that is very much the way to go. In fact, I don't see how we have much choice, given the budget reality.

Senator BOOZMAN. As a commission member, somebody that worked hard and went through a number of different options, finally choosing the Flexible Path option, I am curious. The authorization bill worked hard in trying to push that down the road in order to get done.

I am a little bit confused about the administration's path. And being somebody that is new to the Committee and working hard to understand, the paths that you all tried to explore, where do you see them going as apart from the authorization?

Dr. CHYBA. Well, thank you.

And as you stated, the choice of Flexible Path was not our committee's. I think it was the——

Senator BOOZMAN. Right.

Dr. CHYBA.—choice of the Subcommittee. And I also think that as I read the President's remarks, I think it was essentially what the administration was picking.

Beyond that, since I am here in my personal capacity, and the Committee made recommendations to the administration and ceased to exist in 2009, I am really not in a position to assess the motives of the administration, any more than I am to assess the motives of members of the Committee.

Senator BOOZMAN. No, again, and I don't mean the motives is all. I am just saying that you are in a position. We have got of all these different options. One was chosen. If we move along the path as they would like to do, by their actions, where do you see that going? What is that path?

Dr. CHYBA. Well, without trying to speak for the administration, again, just speaking of my own impression of the Flexible Path. You know, it remains to be proven that we can really do this. That is the first thing I would say.

I very much hope that we can because I very much want to have a human future in space beyond low-Earth orbit. But we haven't done this successfully before, where we have kept flying. We are maintaining the station. We are developing capacity to continue launching. We are going to have a gap where we can't do that. And we are developing a heavy lift vehicle and trying to go beyond low-Earth orbit with the kind of budget that we are talking about.

So the first thing if you ask me about where is it going, the first thing we are going to find out is can we really do it? And that, to me, seems like an enormous challenge. And it is going to require I think the Committee's phrase might be "all hands on deck" and, I hope, an unprecedented kind of cooperation between the Hill and the administration and NASA, where the sides are not recalcitrant and they are not hectoring, but they are rolling up their sleeves and working together on an important national objective.

It seems to me that given the budget constraints, the first thing that we can hope for with heavy lift is that we do things in what is called cislunar space, that we get beyond low-Earth orbit, but we don't initially get farther than the Moon. Not to land there, because that is a much more ambitious undertaking, but we just demonstrate once again that with our new system we can get there.

We would need to develop—and assuming that Orion is the vehicle that we are doing that with—we will need to develop an airlock, so that astronauts can leave the capsule. We will need to develop some kind of deep space habitat, so that it would be a modest module that could accompany Orion so that astronauts on longer missions would have more space.

And then, I think we have to look for objectives that are new and interesting, that maximize these other benefits, including scientific knowledge. Not kidding ourselves that this is the best way to go about it scientifically, but if you are going to do it with humans, let's maximize these other benefits.

And I suspect that it is likely that those next missions would be a mission to a near-Earth asteroid. That would be unprecedented

in mission duration and ambition. And it also is related to another important objective, which is protecting human civilization, because we know that these objects occasionally hit the Earth. We had a 15-megaton explosion in Earth's atmosphere that flattened 800 square miles of forest in 1908 over Tunguska in Siberia. These things happen. And they have happened this—well, previous century, but 100 years ago. Learning more about asteroids is in everybody's interest. So I think that makes sense as the next objective.

And then beyond that, there is another much more ambitious hurdle, which is to start thinking in terms of missions that go as far as Mars. And I would hope that the longer-duration asteroid mission would proof the systems that we would need to get out that far, again without having to pay up front for the enormously expensive capacity of actually landing.

You know, I think Flexible Path is clearly kicking that can down the road because it is not clear how we are going to pay for the development of those much more expensive systems, given the current budget. And I think there is a hope there that down the road somehow that changes.

There is also a kind of off-ramp in Flexible Path. It is called the "Flexible" Path. If the Nation decides that returning to the surface of the Moon is an important objective, and that could be for a variety of scientific or political reasons, the point of the Flexible Path is to get the necessary infrastructure in place—everything short of the landers themselves—so that we could then, if we need to, make that decision and divert the Flexible Path toward the Moon. That is why it is flexible.

Senator BOOZMAN. Thank you, Mr. Chairman.

Senator NELSON. That was a very clear fleshing out of the concepts behind the Flexible Path. And I appreciate you putting that on the record, Dr. Chyba.

And I appreciate also you drawing the attention to Appendix B of NASA's report. And I will just quote from that appendix where, as you had said, that they had said that—in this particular case, they used the Falcon 9 as the example of a commercial rocket being developed for $400 million. And I quote, "Thus, the predicted cost to develop a Falcon 9, if done by NASA, would have been between $1.7 billion and $4.0 billion."

And they go on to say SpaceX has publicly indicated that the development cost for Falcon 9 launch vehicle was approximately $300 million. Additionally, approximately $90 million was spent developing the Falcon 1 launch vehicle and so forth, which brings it up to the total that you were talking about of $400 million.

Now, if this bears out that there is that much difference, then it certainly corroborates the Flexible Path and the philosophy of the authorization bill. And so, to Mr. Pulham and Mr. Slazer, whereas it appears in the past that we have seen a decline in American competitiveness in the commercial marketplace, with Mr. Culbertson's company as another example, and many others out there competing, they are going to be launching cargo to the International Space Station on American rockets, and it is going to start this fall. So tell me, Mr. Pulham and Mr. Slazer, what do you think

is the possibility of the turnaround of increasing our share of the commercial marketplace?

Mr. PULHAM. Thanks, Senator.

I think it is actually very good. I would start by observing that I have never had any doubt that commercial companies could do things cheaper than the government can. I think when you look at how NASA operates, it operates under a lot of requirements that a commercial company does not have to meet in terms of its oversight, its many political masters, its historic requirements around issues of management and safety.

I am very, very pleased with how SpaceX has done. As a matter of fact, the Space Foundation awarded SpaceX its Space Achievement Award for 2010 at our National Space Symposium just a little bit more than a month ago.

I think this does pose some interesting scenarios for us. I think that a successful SpaceX, or successful Virgin Galactic, name one, I think those are game changers for us. I think that they fundamentally change the ability of our foreign competitors, if you will, in the launch business. But that assumes, of course, a fair playing field.

The current problems we have with ITAR and export controls do create an artificial barrier that says that until those are fixed, it does still become difficult for a company like SpaceX to market overseas because those overseas payloads coming to the United States to be launched triggers an ITAR event that adds expense and may either price them out or simply keep them out.

I am not sure if that is the answer to your question. I would also, with your indulgence, just make a comment on the NASA evolving various things like the SSME and others for the heavy lift. I think that is fine if we agree that what that heavy lift vehicle is going to do is enable us to do other things that require new technologies, innovative thinking, and so on.

The concern that I have is—one of the things that the Apollo Program did was it asked us to do difficult things that had never been done before, and that resulted in a lot of invention, a lot of new technology. If we are depending on existing technology and not interested in developing new technology, I think that is something that bears a look at as we implement this plan.

Senator NELSON. Well, thus, the flexible path, which Dr. Chyba outlined. In the NASA authorization bill, you have a flexible path going forward to get components up into Earth orbit. And then, depending on what your particular goal is, at that point you develop the technologies to get there.

We are not going to Mars or likely to an asteroid at this point with the technologies that we have. It is going to require all kinds of new things.

Captain Culbertson, since the subject of this hearing is the contributions of space to national priorities, you mention all the nations that are participating in this gargantuan thing that is on orbit called the International Space Station. And you mention also this extraordinary relationship that we have with the Russians that was born out of the beginning of the thaw of the Cold War when an Apollo spacecraft rendezvoused and docked with a Soyuz spacecraft in 1975 in the middle of the cold war.

And they lived 9 days together in space, and that is an extraordinary human interest story to see the relationship of those three American astronauts, now Deke Slayton deceased, and the two Soviet cosmonauts. But you chronicled an additional comment about this relationship evolving into what we see today. Would you want to give us some more comments for the record as a contribution of space?

Captain CULBERTSON. I would be glad to. Thank you.

When the Shuttle-Mir Program was envisioned, it was an offshoot of the decision to bring the Russians into the International Space Station as a partner. The Mir was already on orbit. It had been there since 1986. They had operated it almost continuously during that time with two or three crew members on at a time.

They had learned to operate the station basically. We had not yet flown a station other than Skylab, which was operated for a maximum of, I think, 87 days at a time. And so, it was an opportunity for us to participate with someone who was already doing this, but also because they were being brought in as an important partner, providing significant segments of the station that would allow it to be viable and operate, it was important for us to learn to work with them before we started putting pieces together in orbit.

So, together, we built a docking module, which allowed the Shuttle to dock so that we could more easily attach to the Mir Space Station, more easily transfer people. We developed logistics capability within the Shuttle to carry not only our crew members, but also the cargo associated with their experiments, and also to supplement what was going on on the Mir as a cooperative partner.

To do all of that, we had to learn each other's way of doing business, each other's way of doing engineering, each other's way of doing operations. We had to basically live in each other's control centers, each other's factories and, eventually, visit each other in their homes.

And at the working level, at the management level, it became a very close-knit, tight team that was able to deal with almost any problem that came up, including the life-threatening ones that occurred during the program. That literal trial by fire allowed us to develop the trust that was necessary to go from there to the International Space Station because, at this point, we do depend on each other.

Neither of the two countries could go it alone on ISS at this point. And the other partners depend on both of us to do our part to keep it working and to keep it as a valuable research station. And so, that development of that relationship was critical going forward.

If I could expand on that just a little bit, the relationships that we are developing now within this country in the commercial world in relation to what NASA is doing is a development of something critical that goes beyond the technology and the hardware that is being built. And understanding how to bring commercial practices to development of spacecraft and rockets that will make things more cost effective, but bring in the lessons learned of NASA, the oversight in the key areas of the decades of flying people in space, of flying hardware in space, and combining those two makes it a very valuable experience.

And so, we cannot overlook the relationship and operational capabilities that we are developing as we are going forward. And I would like to see that continue.

And so, engaging with the Russians, to finish answering your question, was critical to being successful in the station. We learned a lot about each other. We overcame politics that still, to this day, sort of overlay everything but allow us to make a phone call between program managers and make a decision in a few minutes on what needs to be done in the next hour to keep the crew safe.

Senator NELSON. And we often forget that when we talk about the contributions of space to national priorities, which you all have very eloquently outlined, the technological spinoffs and so forth. But the one that Captain Culbertson has just mentioned was and has been invaluable.

Yes, sir?

Captain Culbertson: If I could just add, the first time two components were put together, one was a Russian, one was an American component. They had never touched each other prior to going into space. And they were attached going 18,000 miles an hour in a vacuum and fit perfectly the first time.

And that has been true of every component between our various countries that we have taken up there because we have worked on, first of all, the trust and, second, the communication that allows us to understand each other's capabilities, each other's hardware.

And it allows us to know more about each other as a people, too, both ourselves and the people we are working with. And I think that, in itself, helps make us good leaders, and it helps keep the peace where we can in the world.

Senator NELSON. Well said.

Senator Hutchinson?

Senator Boozman?

Senator BOOZMAN. Thank you, Mr. Chairman.

Mr. Slazer, what actions do you believe that Congress could or should take that would enhance the ability of the U.S. aerospace industry to continue its record of supporting the nation's technological superiority, innovation, and competitiveness in the global economy?

Mr. SLAZER. You know, to follow up on Elliot's earlier comment relative to exports, satellites were put on the munitions list, one of the few—maybe the only thing, except for overt weapons, that was ever put on an munitions list. And its regulation has caused or helped cause the decline of U.S. market share in commercial satellites from about 70 percent down to 25 percent. It is up a little bit lately, but it is still well below its historic norms.

On the component level, when I used to work on Delta launch vehicles, we would have clamp bands from Sweden. We would have nozzle extensions from France. Other competitors would have fairings from Switzerland and other countries in Europe.

We don't export. We have such a difficult time exporting hardware. And some of the suppliers that we have in the U.S. industry are the best in the world and could compete, but for the difficulty of getting things to be exported.

And so, I think that when we look at a national export initiative, you have to look at where is your sustainable industry, where do

you really excel, and try to make those industries excel. We excel in aerospace and overall aerospace. I should note the fact we are the largest contributor to the balance of trade and in the surplus category about $53 billion last year.

But it could be more. It could be more on the space side, if we could look at the roles—and the other thing I would offer is that that would make us better in two other ways. One is to maintain an industrial base requires a certain level of activity. To the extent that exports could be part of that level of activity, it would make it easier for the Air Force and for NASA to not have to spend so much for what they get from the industry or to try to maintain capabilities.

It would also make us better competitors. One of the reasons why our IT industry is as good as it is, is there is a lot of competition. Boeing is better because there is an Airbus than if there wasn't because the two of them are constantly trying to outdo the other.

And so, by having an industry that is allowed to compete, we wind up with lower costs. We wind up with an industry that is forced to be better. And I think that is one of the best things we could do is reforming our export regime.

Senator BOOZMAN. Very good. Thank you.

Mr. Pulham, what role does NASA's munitions play in America's leadership in space?

Mr. PULHAM. Senator, I think there's a number of things. Clearly, as I discussed in my remarks, the impressiveness of what we have done, contributing to our soft power and our leadership as a nation—you know, whether it was the Apollo-Soyuz, whether it was Shuttle-Mir, you know, when we do these things, there are technical aspects. There are financial aspects. But the message that we send around the world about what kind of a nation we are, that we are a nation of leaders, that we are a nation of great technological prowess, really causes the world to view us in a way that they would not if we could not do those things.

And so, I think the contribution of NASA to soft power is just paramount. But I also think the contribution that NASA makes to the intellectual capacity of this nation is not totally and thoroughly understood and I wouldn't pretend to totally and thoroughly understand it, but I do know a few things.

That is that students, whatever grade level—and believe it or not, we are teaching space in pre-K now—they grasp what is going on in space, they grasp what NASA is doing, and then they get very excited about it, and that changes fundamentally the way that they look at the study of things like science and engineering and mathematics.

We have referred to this Jack Swigert Aerospace Academy. We have students who are—94 percent of those students are on free or assisted lunch. Most of them have never touched a piece of technology before. And now they come in, come down to our laboratory, and use space sensors and space software to measure distances on their campus and figure out where everything is in relation to their own lives.

The other part of the education piece then becomes what do we do at the college level? And I think one of the things that NASA is not greatly appreciated for is the amount of investment that

NASA makes in the university research and graduate studies at our universities and how that influences some of the career decisions that people make when they are in graduate and postgraduate school.

Our organization is international, but we are headquartered in Colorado. And I am conscious of the fact that the University of Colorado, of all institutions, has traditionally been one of the largest recipients of NASA research dollars. And because of that, we have developed a center of excellence in the northern part of the state in satellites, in sensors, in manufacturing—aerospace manufacturing, and so on.

And so, I think NASA plays a real, real important role. And I think we need to work on ways to have whatever NASA is doing be more visible to the American public so that the American public can embrace all the benefits of this activity.

Senator BOOZMAN. OK. I want to follow up with asking you about if we don't aggressively move forward and begin work on the heavy lift rocket and the Orion crew, what affect that is going to have in our international space leadership.

And then, secondly, Dr. Chyba, you can think about this, because what you alluded to I think is so important, Mr. Pulham. If you would comment, Dr. Chyba, about your perspective from an academic experience what you believe is the best way to attract students and interest them in the fields of study that are needed for maintaining a strong and effective space exploration program.

Mr. Pulham and then Dr. Chyba.

Mr. PULHAM. Thank you, Senator.

I think that in terms of the importance of having a new heavy lift vehicle, you really only need to look as far as the James Webb Telescope Program to understand where we are. The James Webb Telescope, when it is finally put into orbit, will be put into orbit on a European vehicle, the Ariane V, because that vehicle is capable of taking the Webb telescope and putting it in insertion to get it to the Lagrangian point where it is going to be stationed.

Having that kind of capability, that kind of upmass of a large vehicle really enables you to do things we can't do now. You know, the Space Shuttle can carry a huge module of 40,000 pounds or so, but you know, if you had a capability of putting 200,000 pounds in LEO or taking that 80,000-pound payload and putting it on a trajectory to the Moon, that is a real game changer.

And so, I think it is important for us to get that heavy lift capability just as quickly as we can.

Dr. CHYBA. Senator, thank you.

There are a few comments I would make. One is a broad one that over my career as a planetary scientist, I have had the opportunity to talk to kids at all levels from first grade up through, of course, graduate students. And so, my first comment is, in effect, a very broad one, and it is something I noticed when I started doing this when I was in my 20s, was that there was enormous enthusiasm for space. And I see that in my son's daycare currently—enormous enthusiasm for space when kids are young.

And somehow by the time you are talking with the high school kids, it is a very different level of enthusiasm. And that isn't NASA's problem. I think that is a broader societal issue. Somehow

we are squeezing that enthusiasm out of too many of our students. And we need not only to speak to those students who are going to make aerospace or science their career, but we need to speak to our whole population and keep them excited about science.

A second comment I would make is the importance of honesty, of what I called scientific integrity. And this is why I pushed for it in the Augustine Committee report. The students that are in college or especially in grad school, especially the ones in grad school, they can really smell it if they feel like they are being told a story about the space program that doesn't stack up scientifically, if claims are being made that this or that mission will lead us to a cure for cancer when the connection just clearly isn't there, that really immediately translates into deep cynicism and skepticism about the program. And I have seen that too often.

A third comment is that the program needs to be not only doing exciting things, it also needs to be seen to be at the cutting edge of what is happening. I had a tremendous graduate student in aerospace at a major university who worked with me for a year. He was one of the best students I've ever had—really sharp. I mean, did stuff that I didn't expect him to do, did stuff that showed that he would come in the next week and show me why what I was doing was wrong. It was just terrific.

And he didn't want to go work for NASA. He wanted to go work with one of the space startups. And my sense from talking to him was that he felt like NASA had become kind of a dinosaur. And this left me disheartened and feeling sad for my country.

I am glad the startups are there, but, by God, we need a NASA that also makes students feel that way about it. And the idea that our best and brightest would be ruling out NASA because it is not exciting enough, there is something deeply wrong in that. That is just an anecdote, but for me, it was a powerful one.

I have hope in that respect because in the Augustine Committee, we rolled up our sleeves and worked very closely with NASA engineers and NASA managers. And because I know that there has been at times a difficult relationship, and some of that has been referenced in this hearing today, I would like to just say for the record, if I may, that so many of those people are the absolute best in the world. And they are deeply dedicated.

So there ought to be—I mean, there is at NASA not only a reservoir of deep knowledge and dedication, the best in the world, but also deep motivation to make this happen. That is why they are there. So I really hope it is going to be possible, moving forward, for there to be a cooperative environment in which all sides work together and roll up their sleeves to achieve this major national objective. And I think students will see that.

Senator BOOZMAN [presiding]. Thank you very much. I think that is very well said, and I really believe with all of my heart that we will see that happen.

We appreciate you all being here so much. This has been a very good hearing, very informative, very helpful. And we look forward to working with you in the future.

On behalf of our chairman, the meeting is adjourned.

[Whereupon, at 12:26 p.m., the hearing was adjourned.]

A P P E N D I X

PREPARED STATEMENT OF HON. JOHN D. ROCKEFELLER IV, U.S. SENATOR FROM WEST VIRGINIA

Next week is the 50th anniversary of President John F. Kennedy's historic address before a special joint session of Congress. In that address, the president famously challenged the Nation to send a man to the moon.

While best remembered for its "Moon Challenge", the address also offered a vision for space exploration. Fifty years later, this vision has paid off in ways that neither he, nor the nation, could have fathomed at the time.

Yes, we've sent hundreds of people to space. And yes, we've erected a national laboratory 200 miles above the Earth. We've even begun to unravel the mysteries of the universe by deploying the Hubble space telescope.

But America's space exploration has meant much more than just going to space. The technology we've developed to get there has led to new innovations, new breakthroughs and new discoveries. And this has helped make America prosperous, inspired future generations of scientists and engineers, and boosted our economy.

The Space Shuttle Program alone has generated more than 100 technology spinoffs, including miniaturized heart pumps, laboratory instruments that allow faster blood analysis, hand-held devices that warn pilots of dangerous or deteriorating cabin pressure, and prosthetic limbs that are lighter and stronger.

The list goes on and on—and that's just technologies derived from the Space Shuttle Program. Our space exploration has led to countless discoveries which save and improve lives here on Earth. For all those reasons, and more, it is critical that we maintain our space leadership. That's what members of this Committee have fought to do.

Last year, we drafted and passed legislation that laid out a carefully considered bipartisan vision of the best path forward for NASA. It was a vision that enabled ambitious investments in science, aeronautics, education and human space flight exploration, while also recognizing current budgetary constraints. It laid out a new way for NASA.

More than seven months after President Obama signed this bill into law, I am concerned NASA is not moving forward with implementing it with the urgency it requires. I'm worried that NASA's inaction and indecision in making this transition could hurt America's space leadership—something that would cost us billions of dollars and years to repair.

It is for this reason that I'm prepared to step up the Committee's oversight today.

This morning I, along with members of this Committee, sent a letter to Administrator Bolden. The letter outlines steps NASA should to take to help this Committee determine whether it is fully implementing the law. As I've said before, implementation of the law is a priority for me, and for this Committee. We simply can't afford to get it wrong.

I look forward to hearing more from our witnesses today about the impact of space investments on our economy, national security, technological innovation and global competitiveness. And I look forward to another 50 years of U.S. space leadership.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. KAY BAILEY HUTCHISON TO CHRISTOPHER F. CHYBA, PH.D.

Question 1. Dr. Chyba, as a member of the Augustine Human Space Flight Plans Review Committee, how would you assess the progress made in the Nation's exploration policy and specifically its human space flight policy since the Committee completed its report?

Answer. Much of the political response within Washington, D.C. represents good progress. The Obama Administration chose the flexible path from among the options presented to it by the Human Space Flight Plans Review Committee, and this was the approach that scored highest according to the twelve metrics our Committee

used to rank the different options. This included, contrary to the Constellation Program's unbudgeted plan to terminate the International Space Station (ISS) in early 2016, continuing that program out to 2020 and probably beyond. Had that decision not been reversed, the United States would truly have been on a path to terminate human spaceflight in the middle of this decade. The Administration also endorsed commercial crew, consistent with our Committee's vision of the commercial sector "filling in" behind NASA as NASA focused on the forefront of exploration beyond Low-Earth Orbit (LEO). Finally, and also consistent with our report, the Administration emphasized investing in advanced technology that could enable future exploration.

Then, in its 2010 Authorization Act, the Congress broadly endorsed a flexible-path approach to future exploration, it endorsed the ISS extension, and it endorsed commercial crew. Congress also instructed NASA to build a heavy-lift rocket, relying as much as possible on Shuttle and Constellation designs. This is consistent with the Committee's vision of NASA focusing on the most demanding aspects of exploration beyond LEO.

Where progress has not been made, vis-à-vis the Committee report, is with respect to budget. As I discussed in my testimony, the Committee emphasized that NASA has not been able to afford to simultaneously fly missions and develop and build a new human spaceflight architecture since the 1960s—and the human spaceflight budget, in real dollars, was double in the 1960s what it is today. Even with Shuttle termination, the United States will continue to pay for astronauts to fly to the ISS, and of course continue to bear costs of ISS operation. The Committee concluded that in order to continue to fly to the ISS while also developing the systems needed to go beyond LEO, NASA's human spaceflight budget would need to be augmented by something in the neighborhood of $3 billion per year.

The Obama Administration did not ask for this augmentation, but instead chose to emphasize commercial space and technology development as a less expensive path that could help enable future exploration beyond LEO. In contrast, the 2010 Authorization Act instructed NASA to have operational capability of the core elements of a heavy-lift vehicle by the end of 2016. As I said in response to a question during the hearing, it's unclear to me whether we will be able to do all this. If we are going to design and build new heavy lift under severe budget constraints, I support the creation of a Shuttle-derived vehicle (and in particular, what was sometimes called "Direct"), even while recognizing that this approach is likely to have higher recurring costs down the road. Designing and building heavy lift under the present NASA budget, and to any particular deadline, represents a great challenge.

Question 2. This Committee and the Congress developed what was, in effect, a response to the Augustine report in the form of the 2010 NASA Authorization Act. That Act, as you know, represented a carefully constructed compromise approach between those who wanted to simply continue the Constellation program and those who essentially wanted NASA out of the human spaceflight business for the foreseeable future, at least in accessing low-Earth orbit. As you have heard in Committee Members' opening statements, there is considerable unhappiness with the seemingly sluggish response of NASA and the Administration to implement the requirements of that Act, and special concern at statements that suggest further "study" is required. Do you believe any additional "study" is really necessary? What is there that has yet to be studied by NASA in your view in the way of potential launch vehicle configurations and technologies or other matters prior to establishing a path forward for U.S. human space flight?

Answer. My response to Question 1 provides the context for my response to this second question. It will likely prove very challenging to develop a heavy-lift vehicle under the current budget on a prescribed schedule while simultaneously conducting astronaut operations and supporting the development of commercial spaceflight.

In response to a question at the hearing, I noted something that I certainly hope will receive further study. The Subcommittee on Science and Space had just been given a commercial market assessment from NASA that was requested in the 2010 authorization bill. There is a one-page appendix, Appendix B, in that market assessment that it might prove very useful to examine in detail. In that appendix, NASA does a cost evaluation of the Space X Falcon 9 spacecraft. NASA costs out how expensive it would have been for NASA to have built that rocket. And with two different assumptions, they get an answer of $1.7 billion at the low end and $4 billion at the high end. They also state that they examined and confirmed SpaceX's costing of it, and it cost SpaceX $400 million.

We should understand if this conclusion is correct, and if so why would it have been between 4 and 10 times more expensive for NASA to develop the Falcon 9 than was the case for Space X. This is all the more important if one of the issues facing

NASA right now is how to develop the heavy launch vehicle within the budget profile and timeline that the committee has given it.

Question 3. Another key issue of interest and concern is the role of technology development in ensuring safe, efficient, and supportable space exploration. That also has implications for the transference of new technologies to the private sector. In your view, is that technology development best done with open-ended or little mission focus, or is it best done in the context of meeting specific capability requirements (*i.e.,* tying that development to say exploration mission needs for fuel transfer or other specific needs)? Is there a balancing point between these approaches to technology development?

Answer. It seems likely that a balance will be required. Some new technologies are potential game-changers, or at least game-evolvers, almost whatever approach the United States takes to going beyond LEO. Fuel depots (which come in several varieties of increasing ambition and capability) may be the premier example of such a technology. Moreover, their development and utilization will help establish a demand-pull for commercial spaceflight, which is in itself likely to be an important component of a successful human spaceflight program. At the same time, there are certain technologies that are clearly specific to particular mission plans. An important example is that we currently do not know how to protect astronauts sufficiently against radiation during the long-duration missions that would be needed for a human mission to Mars and back.[1] This is currently one of the biggest challenges to such a mission. But were we to decide, for example, that a human mission to Mars was either not on our future agenda at all or else many decades in the future, the technologies that would be explored and developed to address this problem could be put aside for the time being. Undoubtedly there are many other such examples.

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. JOHN BOOZMAN TO CHRISTOPHER F. CHYBA, PH.D.

Question. What do you believe are the areas in space exploration that are best undertaken by cooperation, as opposed to competition, among the space faring nations of the world?

Answer. In both the scientific exploration of the solar system using robotic spacecraft, and in the human spaceflight program, I believe that we will be best served by robust efforts to increase cooperation with other spacefaring nations. We have a model in the International Space Station for how to manage such cooperation. Of course there are national security concerns that must always be evaluated, and which may place specific limitations on certain aspects of cooperation. But in general, human spaceflight—especially spaceflight beyond Low Earth Orbit (LEO)—is so expensive that cooperation would be a wise way forward. While competition drove the Apollo program to the Moon, I do not believe that this provides a model for future human exploration beyond LEO that is likely to succeed or prove sustainable.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. KAY BAILEY HUTCHISON TO FRANK L. CULBERTSON, JR.

Question 1. What do you believe are the most significant challenges facing the country and our international partners in maintaining and servicing the space station?

Answer. NASA's technical experts have looked carefully at all contingencies and recognize that in operating the International Space Station, there are risks such as a micrometeroid hit, collision with space debris, or a failure of the regenerative Environmental Control and Life Support System (ECLSS) which would require the ISS to be depopulated. NASA and its international and commercial partners are working hand-in-hand to ensure that we minimize these risks as best as possible.

Question 2. Since this hearing is focusing on the global space economy and the contribution of space to meeting national needs, what do you believe are the most important aspects of our space program in helping to meet critical national needs and priorities?

Answer. As I indicated in my formal testimony to the committee, our national space program provides outsized benefits to our nation, compared to what we invest in NASA. The conduct of our space program enhances American "soft power"—the

---

[1] Norman R. Augustine, Wanda M. Austin, Christopher Chyba, Charles F. Kennel, Bohdan I. Bejmuk, Edward F. Crawley, Lester L. Lyles, Leroy Chiao, Jeff Greason, and Sally K. Ride, *Seeking a Human Spaceflight Program Worthy of a Great Nation,* October 2009, p. 100.

ability of the United States and our partners to expand our influence and capabilities because of the attraction of our values, goals, and technological leadership. The space program helps spur economic growth through its employment of hundreds of thousands of skilled high technology workers, its positive contributions to our balance of trade, and through the development of spinoff technologies that lead to significant benefits to society in the areas of health and medicine, transportation, public safety, consumer goods, environmental and agricultural resources, computer technology and industrial productivity. When we make the next great leaps in space, we will be able to incorporate the vast resources of the inner solar system into our economic sphere. In this regard, the International Space Station is an ideal platform for conducting valuable scientific research and for developing and simulating the operations, technologies, and techniques for executing more ambitious and lengthy missions to the Moon, Mars, and other destinations. Finally, through the space program we continue to inspire the next generation of explorers, scientists and investors, and make fundamental advances in knowledge about our planet, the solar system and the universe. Great nations do great things, and the space program is one of America's most noble and productive pursuits.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. KAY BAILEY HUTCHISON TO ELLIOT HOLOKAUAHI PULHAM

Question 1. What do you believe are the Nation's most significant short-term and long-term challenges with respect to maintaining leadership in space?

Answer. Thank you for the opportunity to address further questions on national imperatives in space. There are many short-term and long-term challenges that the United States faces at this critical time in its national space endeavors. In the short term we face several problems related to the drawdown of U.S. space capabilities as a result of the poorly planned retirement of the U.S. Space Shuttle. The largest and most urgent challenge has to do with the loss of thousands and thousands of highly skilled workers who have dedicated their careers to the advancement of America's space goals and objectives.

Due to exceedingly poor planning on the part of NASA, these highly trained, well educated and loyal workers are being laid off at an alarming pace, and with no apparent concern on the part of their government for their well-being, their livelihood, the sacrifices they have made for their country, or any prospect that the U.S. space enterprise will wish to retain their unique skills. Many of these highly educated and very valuable workers have been alienated, and, indeed, pushed to the point of desperation. Despite their love of country and love of what they do it is highly unlikely that the best and brightest of these Americans will trust the space enterprise adequately to return to the workforce even if the opportunity to do so presents itself in the future. It is absolutely imperative the United States embark on a course of action to restore its leadership in the global space community. The men and women we would rely upon for this task simply will no longer be there.

Further, the very act of launching humans into space is no longer within the capabilities of NASA. For the country to have invested an estimated $100 billion building and operating the International Space Station (ISS) to which it no longer has sovereign access is simply unbelievable. When NASA announced its plans to depend upon Russian vehicles to service the ISS I was shocked at the space agency's apparent lack of understanding of the situation and the vulnerabilities this plan introduced. I predicted a catastrophic loss of control over our ability to carry out our own human spaceflight programs. Sometimes, I hate it when I am right, as you all know, with the recent failed Russian Progress mission, the ability of Russia–upon whom now we are totally dependent–to launch humans and cargo to the ISS is in grave peril. For the long-term, the picture is also bleak with regards to our leadership in space, however, given leadership, financial resources, and political resolve, I believe that we can recover our long-term prospects. Clearly, NASA has painted itself into a corner from which there is no quick or inexpensive escape. Commercial launch services providers are making tremendous progress in preparing to assume responsibility for routine access to and from low Earth orbit. To some extent this work could be accelerated with additional funding. However, funding alone will not address all the challenges to replacing NASA's inherent spaceflight capabilities with commercial ones. Further, when we consider the NASA mission to explore the universe, we are clearly talking about space transportation beyond Low Earth Orbit. Considering the current tug-of-war among NASA, the Congress, the White House, and other interested parties, America's future as a heavy lift launch provider and as a nation of deep space human explorers is very much at risk.

Question 2. What are industrial and market benefits of U.S. leadership in space? What is at risk if that leadership is lost?

Answer. As you know, there are tremendous industrial and market benefits associated with U.S. leadership in space. For the past 50 years space has served as a fundamental economic engine propelling the United States forward by creating new technologies, which in turn lead to entirely new industries, which in turn lead to outstanding jobs and careers for people and to fundamentally sound business opportunities for our economy. The period of time in which this economic engine was operating at its highest potential was that period of time leading up to the Apollo program, when innovation and invention were absolutely required in order to succeed with the Apollo mission. As a result this Nation challenged itself to do the difficult things that had never been done before, to engage our best and brightest minds in ways that they had not been engaged before, to challenge our society as a whole to envision itself as greater than it was, and to dream of a better future. We succeeded. Sadly, however, we have not pursued our space programs with such determination since the Apollo program was terminated. Being stuck in Low Earth Orbit has meant that we have shifted the transmission on the economic engine that is space from high gear, overdrive, to compound low range–some would say idle. The benefits of being a leader in space go far beyond the economic and technical benefits. There is a significant diplomatic advantage to being the only nation capable of putting humans on the moon. There is a significant advantage in recruiting the best and brightest young minds from around the world when you have a vibrant space program in place. A there is a significant advantage that accrues to the very spirit of the country when we are pursuing daring adventures and difficult goals. These advantages have been lost to us as we have maintained a budget driven space program that has been stuck in low Earth orbit with no place to go, and now seems incapable of even reaching low Earth orbit.

Question 3. Your most recent edition of The Space Report describes an enormous jump of bachelor's equivalent graduates in China. As a matter of fact, in 2006 China graduated more bachelor's equivalent students than the United States, 5 of the largest European Union Nations (France, Germany, Italy, Spain, and the U.K.), South Korea, and Japan, combined. Do you have any specific information that would suggest what is driving this large increase?

Answer. To a significant degree, the large increases in the graduation of engineering students in China, India, Japan and other nations can be attributed to the excitement that the people of those nations feel about the grand and daring pursuits of their nations in space. This is, quite simply, the "Apollo effect" that other nations have long coveted and which we, the United States, seem to have forgotten. There is immense pride in these nations associated with their accomplishments in space. This national sense of purpose inspires greater and greater numbers of students to enroll in the difficult courses associated with science, technology, engineering, and mathematics–the STEM disciplines. And just as American aerospace engineers diversified into information technology, high-technology consumer products and other challenging and rewarding fields, engineers in countries like China are being inspired and motivated by their national space programs, and when not contributing to those find themselves engineering rail lines for the fastest trains on the planet, complex hydraulic systems for the largest dams and hydroelectric projects on the planet, etc. I should add all those great things that the United States used to be known for doing are now being accomplished by other people, in other places because of a national vision and inspiration that has gone missing in our own country.

Question 4. Your statement provides a number of excellent examples of how U.S. national investments in space have proven to be "high-impact investments of tremendous national benefit," and that "the U.S. aerospace industry . . . by some estimates accounted for 50 percent of the new wealth generated in America between 1962 and 2002." You go on to say that the aerospace industry "built its muscle" on several programs you list, all of which are human spaceflight programs. Is there something unique about human spaceflight programs that lead to the development of more "industrial muscle" than other kinds of space programs?

Answer. Yes, there is something unique about human spaceflight programs that lead to the development of more industrial muscle than other kinds of space programs. Robotic programs are fine and have their place; indeed, robots are better suited to many space missions then are humans. But we must ask ourselves whether, if Sir Edmund Hillary had elected to catapult a robot to the top of Mount Everest, would we have considered the mountain conquered, would we have considered it a human achievement, or would we simply not have cared? Humans are essential to the space exploration endeavor because at the end of the day exploration is a human endeavor. And because humans are involved in this very dangerous enter-

prise, the level of engineering, development, design, test, innovation, invention, test and retest, and all the other things that result in capabilities that never existed before must be part of the process. There is no other way to drive this level of excellence other than with humans in the loop. And so industry is challenged in ways it has never been challenged before, and in ways it would not be challenged were humans not involved.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN BOOZMAN TO ELLIOT HOLOKAUAHI PULHAM

Question 1. From your organization's review over the years of technology transfer, or spinoffs, from space-related development activity, what is the most effective mechanism for ensuring the maximum dissemination of technology for industrial or commercial applications?

Answer. The first thing that is required is that advanced technologies in are being developed, which requires a challenging mission and technical capabilities that are not currently in inventory. Assuming we have a robust and productive national space program, which is, of course, not a "slam dunk" assumption at this point in time, the best way to disseminate this technology is by having the maximum number of people engaged in the enterprise. Those who are inventing and developing the new technologies understand those technologies the best, and are uniquely positioned to see additional uses for the technologies. I often think of an Apollo engineer, Eddie Sturman, who had the simple job of inventing the most efficient valves possible for the Saturn V launch vehicle. On the face of it, not a very "sexy" assignment. Yet Eddie Sturman, because of Apollo, had the chance to design control valves that are so much lighter, stronger, faster, higher-performing, and inexpensive, they have quite revolutionized the state-of-the-art in valves. . .and valves are in everything! The result, a company called Sturman Industries, today co-produces some of the most fuel efficient and powerful automotive engines in the world. The same factory produces valves that have led to the introduction of draft-beer-at-home packaging solutions for the beverage industry. And you couldn't have just thought this up. You had to be there, like Eddie Sturman was there. I also think about the inventor of the cochlear implant device, who took the technology and software developed for the space shuttle program and adapted it so that a completely deaf person can hear clearly again. The invention was made possible because a person was involved in a NASA program who understood the possibilities of the technology in front of them and took that technology to the next level—enabling thousands of people around the world to hear normally. So, on the one hand, I have little doubt that technology transfer offices, NASA publications like "Spinoff," public awareness programs like the Space Foundation's very own Space Technology Hall of Fame, and other dedicated efforts indeed help distribute these technologies and build new industries. On the other hand I fundamentally believe that the secret to pushing new technologies out into the marketplace and out into the world is to have a vibrant space program in which as many people as possible are involved

Question 2. Mr. Pulham, the most recent report from your organization states that the 2010 global space economy is estimated to be $276 billion dollars. What do you believe are the most significant space-based markets emerging today?

Answer. In terms of known markets, there's no question that commercial satellite utilization is both the largest and fastest growing space-based market in the world today. More and more, satellites form the essential infrastructure upon which our society operates. I also believe that the satellite marketplace can be greatly energized by intelligent government procurement decisions. It is no mystery to many commercial companies around the world know how to design, develop, test, manufacture, launch, and operate the most complex satellites possible. This is where I think the government can assist this market most, and that is by not competing with commercial companies. Certainly there are satellites that are required by the United States for national security and other purposes that must be discreetly procured with a high degree of specialization. However, the vast majority of U.S. government requirements for satellite capability can be satisfied by commercial satellite manufacturers and operators. I often reflect upon the NPOESS satellite program and how poor management and unknown requirements can negatively impact a promising satellite system, forcing it to come completely off the rails, resulting in failure that most of the involved aerospace companies could have managed very successfully had it not been for the way that government drove, or in some cases failed to drive, critical path decisions. I have often said that if the United States government had simply put a request for proposal out to industry asking for an off-the-shelf procurement of satellites to perform the NPOESS mission, a robust and highly

capable fleet of satellites would have been ready for the government in a short period of time, with a high degree of reliability, based upon proven and well understood satellite platforms, delivered on time and under budget, and ready for efficient operation by a commercial satellite operating company. If the government would simply buy commercial to the greatest degree possible, and if the government would allow U.S. satellite manufacturing companies to compete on a level playing field with satellite manufacturers from Europe and Asia, these two simple changes alone would take our industry a great distance toward better economic health, international competitiveness, and long-term resilience and profitability.

The second largest market, at least as far as U.S. companies are concerned, is the United States national security space community—which includes surveillance, reconnaissance, position-navigation-timing, signals and other forms of intelligence gathering, military remote sensing, space weather and many other important capabilities. While not an emerging-market per se, this segment of the market represents a huge opportunity for both the government and the aerospace contracting community. Clearly these systems require exquisite technical capabilities that are not commonly found on non-military platforms; on the other hand it is seldom recognized that commercial satellite manufacturing companies have developed advanced technologies for their commercial customers that could be economically adapted to serve any variety of national security missions. National security space payloads have become so expensive and so time-consuming to develop that not only is "failure not an option" but, the career military and civil service personnel in charge of these systems have become so risk-averse that rapid development, on-time delivery, innovative concepts of operations, and other desirable attributes are largely engineered out of the system. I believe that while there are always going to be satellite systems for national security that must be exquisite single point solutions, I also believe that many of the systems required by either the Air Force, the National Reconnaissance Office, Army, Navy, and other users could be much more cost effectively procured from the commercial satellite manufacturing industry. The savings that could result from this approach not only would contribute to a stronger and more robust commercial satellite manufacturing industry but the budget allocated to national security space programs could be stretched much farther and accomplish much more for our men and women in uniform than what we realize in the current paradigm.

Finally, it must be said, that while transportation is a miniscule part of the overall global space economy, it nonetheless is the part of that economy that makes all the rest possible. I believe that advanced space transportation systems could open up markets and opportunities that, today, are completely invisible to us. At the current cost of putting a pound of payload into orbit, there are not a lot of commercial business cases for space that will close to the satisfaction of investors. However, there are many types of industries that would benefit from access to the space environment. These include pharmaceutical companies, materials and engineering companies, biotech and bioresearch companies, agricultural and other companies. Improving the state of the art in space transportation not only stands to make space utilization more affordable for civil, commercial and national security stakeholders, but will really open up the microgravity environment to benefit agribusiness, healthcare, pharmaceutical, entertainment and other industries in a manner that will benefit industries which at present have little to no space identity that is readily apparent to the public.

Question 3. Your statement discusses the fact that only one of the twenty-five largest satellite communications companies in the world is based in the U.S. In addition, you state that roughly three quarters of all commercial satellites are manufactured outside of the United States. Has there been a trend over time that has led to this disparity? What do you believe is the leading "driver" of this dispersion of activity outside of the U.S.?

Answer. Senator, there is no question whatsoever that the principal driver in this migration of satellite manufacturing and operating capability has been driven by draconian United States export regulations, most specifically ITAR. One may debate from today until the cows come home what triggered the inexplicable clampdown in the export of routine, widely available space technology. At this point in the game assigning blame is not productive, although there is plenty of blame to go around. What would be productive is the return of U.S. space technology export policy to a position somewhat approximating rational behavior. Before the imposition of these draconian export controls, the U.S. manufactured the vast majority of commercial telecommunications satellites. Since that time it has become so difficult to export any satellite technology, even the most innocuous and widely available on foreign markets, that satellite owners and operators have simply seen fit to do business with other manufacturers and other nations who behave more rationally. Similarly with satellite operations, which have changed dramatically as companies like

INTELSAT have changed their structure from international nongovernmental organizations to private for-profit companies, there is no longer any incentive, and indeed there is great risk, to operating in the United States. These companies have contacts, customers, and employees all over the world. All of these aspects of their business are placed in great peril if they choose to operate within the United States. The driver of this trend quite simply is us; we, have chosen to drive it out of the United States.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. KAY BAILEY HUTCHISON TO FRANK SLAZER

Question 1. Many aerospace companies have expressed urgent concern about the lack of a NASA mission and direction. What in your view are the impacts to the industrial base if NASA continues to delay making real decisions with respect to building a heavy lift rocket and a crew capsule?

Answer. As of the time of this response, NASA has made decisions regarding a crew capsule (Orion) and heavy lift system (Space Launch System), which are consistent with the position AIA has taken. AIA has urged the full implementation of the NASA Authorization Act of 2010.

Question 2. I am interested in your thoughts about the impact to other aerospace industry customers from NASA's indecision, delay, or redirection. For instance, with the cancellation of Constellation and the retirement of the Space Shuttle, it's been reported that the Navy recently experienced increases in the price of the Trident missiles, from $10.7 million apiece to $19.2 million apiece, or an 85 percent increase. Are there other "surprises" of this sort in store for other customers?

Answer. Delays in proceeding with new exploration program investments for any reason jeopardize the continuity of our Nation's space exploration program, and risks the loss of crucial skills needed to maintain national space exploration capabilities. Our nation has developed a knowledge base of space systems development that cannot be put on the shelf indefinitely. It is like a muscle—if it is not used, it will atrophy and could be extremely difficult to reconstitute in the future. Worst of all, failure to keep a certain level of activity underway risks disillusioning the next generation of scientists and engineers who will be forced to move on to other technology sectors. This loss would be a tragedy that could mean the new generation loses its opportunity to apprentice with those who designed and built the Space Shuttle and International Space Station forgoing the opportunity to transition the lessons learned to the next generation.

With respect to the collateral damage [the] civil space program decisions have had on the national security industrial base, while AIA is not aware of any imminent cost growth attributable to the Constellation termination decision, it should be noted that similar impacts have happened to NASA. As an example, when the U.S. Air Force made the decision to move all launches to EELV, the Delta II rocket was spelled a death knell due to the diminished market, this despite the vehicle being used for many NASA science missions over the years. This type of unintended consequences is the reason AIA has long advocated a National Space Council in the executive branch, which could bring together relevant Executive Branch entities to fully apprise the interests of all space stakeholders when making significant program decisions.

Question 3. Are there changes in procurement processes used in the space program that the Congress can initiate to enhance our Nation's productivity, effectiveness, and competitiveness?

Answer. Two recommendations immediately come to mind—both of which are institutionally difficult for Congress to agree to. The first would be Multiyear Appropriations for complex, long-term space program investments. This has been done by some of our international space partners, and it would greatly strengthen NASA's ability to manage its programs—especially those involving one of a kind developments, which are prone to schedule challenges despite the best efforts of program management. Not having a stable, predictable funding profile invariably makes it more difficult for program managers to succeed and prioritize their resource investments problems that cascade down into the industrial base. The second change would be to recognize that flat funding profiles drag out development programs and cause higher development costs. For optimal execution, development programs usually need to follow a funding profile with higher expenditures in the middle of the process—even though that could cause NASA's budget to go up for a period of time, the net result, would be lower development program costs overall.

Question 4. In your view, are there shortages of engineers and skilled professionals that are currently impacting the aerospace industry? If so, what are the greatest challenges the aerospace industry faces in retaining experienced technicians and engineers?

Answer. This question has essentially been addressed by my earlier answers—proving program funding stability, allowing continuity for seasoned professionals to pass along the lessons learned, and having a long term commitment to an exploration program will encourage students to pursue careers in those fields which are most needed, and also facilitate retention.

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. JOHN BOOZMAN TO FRANK SLAZER

Question. What do you believe are the areas in space exploration that are best undertaken by cooperation, as opposed to competition, among the space faring nations of the world?

Answer. Historically, successful human space programs have involved internationals either cooperatively as with the Space Shuttle and ISS or competitively as with Apollo. I see the ISS as a great example of how cooperation with nations that share similar objectives as the United States can be a real benefit when pursuing space exploration objectives that are technically challenging and expensive. It is important that the nations involved have shared interests and commitment to make this work over the long run.

Specific areas for cooperation will depend on the specific partners and their respective areas of expertise; for example, Italy has a long tradition of demonstrated performance in providing pressurized structures for crewed applications, and the same is true for Canada with tele-robotics. How international partners could best fit into exploration architecture will depend on the exploration objectives and relative interest and financial commitment of the respective partners. We ought not to enter into partnerships where the fruits of our national investments need to be given away for success, nor should we avoid undertaking development efforts where there are clear benefits to our nation, even if they are costly. Nevertheless, international partnerships are one of the best ways to assure long term program success.

○