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NASA BUDGET AND PROGRAMS: OUTSIDE PERSPECTIVES

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BEFORE THE

SUBCOMMITTEE ON SCIENCE AND SPACE

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION UNITED STATES SENATE

ONE HUNDRED NINTH CONGRESS

SECOND SESSION

JUNE 7, 2006

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ONE HUNDRED NINTH CONGRESS

SECOND SESSION

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NASA BUDGET AND PROGRAMS: OUTSIDE PERSPECTIVES

WEDNESDAY, JUNE 7, 2006

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

The Subcommittee met, pursuant to notice, at 2:34 p.m. in room SD–562, Dirksen Senate Office Building, Hon. Kay Bailey Hutchison, Chairman of the Subcommittee, presiding.

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

Senator HUTCHISON. Good afternoon. We are very pleased that you are here. This is a very important session for us. Certainly my ranking member, Senator Nelson, and I are very focused on this science section of the NASA mission, but I want to especially point out that Senator Sununu asked for this hearing and asked to make this one of the focuses of this subcommittee. So, Senator Sununu, thank you very much for that.

Senator SUNUNU. Thank you.

Senator HUTCHISON. Last year Congress enacted and the President signed the NASA Authorization Act of 2005. This was a bill that I co-sponsored with Senator Nelson and others on the Committee, and it was the first time in 5 years that Congress passed an authorization bill for NASA. It was very important to us that there be a legislative foundation, a commitment to NASA's mission. That is why we thought that the President's vision for exploration should get the Congressional approval and we added parts that came from Congress to make it even stronger.

We believe that we have authorized the minimum funding levels needed to support the Vision for Exploration and the ongoing scientific activities of NASA, including the assembly and full utilization of the International Space Station, in a way that would avoid disruptions caused by any kind of abrupt shift in NASA's focus and goals.

We know that the NASA budget eventually requested by the President is $1.1 billion less than the amount authorized by the NASA Authorization Act. While that is not unusual to have budget requests that are less than the authorized amounts, this is a crucial time for transition. The end result of the shortfall in the funding request is a series of painful decisions for Michael Griffin, the NASA Administrator, and to which, of course, the research community has reacted—and rightfully so.

I am not one who believes that the Federal Government should fund all programs just because we have done it in previous years. We have to have accountability and adjustments to assure that we are making the best use of taxpayer dollars.

I am convinced, however, that in many cases where reductions and cuts have been made in science and research programs in NASA, that we are not justifying the mission that NASA has for rejuvenating the creativity in our scientific community. The underlying value of the things that we have been doing on the Space Station and the missions that NASA has had in science in the past and the positive impacts of those efforts have added to the economic competitive and security interests for all of our country. So I refuse to accept that a fully and adequately funded space program is something that we cannot afford in this Nation.

Finally, there is a practical reason why the President should require that we have realistic funding levels, and that is to succeed in the Vision for Exploration. At a time when the President is working with Congress on a new competitive initiative, which includes doubling the research budget of the National Science Foundation, it would be shortsighted to squeeze the research budget of NASA and other areas of research in the same physical science fields.

We have invited witnesses here today because I believe that we can put our minds together to come up with the funding and to keep the focus on science. I believe that our committee is absolutely solid on this point. We have invited you because you have important opinions on this subject.

We also believe that sharing resources with other agencies of the government who have scientific missions as well could better use the expenditures that we can make in research. That would mean cooperative NASA scientific activities, along with the Department of Defense, DARPA, the Department of Energy, and the National Science Foundation.

In our authorization bill, we did ask those agencies to work with NASA to determine where there were duplications or where putting money together could come to a better result. Finding efficiencies and eliminating duplication, as well as sharing resources for common objectives can help alleviate the pressure for additional funding for NASA, and this is an area that I certainly want to explore.

So I do thank you. After the statements from our colleagues, I will introduce each of the panel members. My Ranking Member, Senator Nelson.

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

Senator BILL NELSON. Thank you, Madam Chairman.

The age-old question, can you have guns and butter in a Nation, and a Nation wants to have both, so too it is with this little Federal agency NASA. Can you have science and human exploration? And the answer is we need both.

We accommodated for that in the NASA authorization bill that we passed last year, but the Office of Management and Budget came along and underfunded the NASA budget by $1.1 billion. So, Senator Sununu, this being a concern of yours, as it is of ours, on the cutting of science programs, we can alleviate that if we can get the appropriators to fund at the authorized level instead of the level that is recommended by OMB.

When you look at a little agency that is less than 1 percent of the entire Federal budget, you are looking at an agency that means so much to the future of the country because of its cutting-edge science exploration and inspiration for the people. That is not, in this Senator's opinion, an agency that you want to go whacking away at its budget.

Thank you, Madam Chair.

Senator HUTCHISON. Thank you.

Senator Sununu.

STATEMENT OF HON. JOHN E. SUNUNU, U.S. SENATOR FROM NEW HAMPSHIRE

Senator SUNUNU. Thank you, Madam Chair. It is a pleasure to be here, and I appreciate all of the effort you have put into both the authorization bill and other issues of science that have come before the Committee.

This is an area that has enormous impact not just on the particular programs that we might talk about today, but I think, as we will hear from the panelists, on focusing the attention, providing a platform for future generations of scientists as well.

And to that extent, I am very pleased to welcome, in addition to our other panelists, Dr. Roy Torbert who works at the University of New Hampshire, who I met probably 8 or 10 years ago when I was first elected to Congress and became familiar with the work that he does at UNH as a professor and a director of the Space Science Center there, working with graduate students and undergraduate students on a range of basic science projects, the very kinds of projects that I think would be most impacted by the budget proposals that Senator Nelson spoke of. They are the kinds of projects that extend the limits of our knowledge in the solar system, the galaxy, and the universe that support our future missions within the space program, and they are the kinds of efforts that simply cannot be done or duplicated anywhere else.

The private sector does not have an interest in this kind of work because it does not have a rate of return, because it does not have predictable future cash-flows, even though 10 or 15 or 20 or 40 years from now someone might say, you know, this is actually a technology that was first used on a particular Explorer mission. No one can predict that today. No one can predict future practical applications or market applications of these technologies. No one else would do this work if government did not step forward and say we have an interest in providing the support for this scientific exploration.

So I think that is the essence of the concerns shared by the members of this subcommittee and I think by our panelists as well. Dr. Torbert has really been a great advocate for those areas of scientific investigation, but also a good teacher, a good administrator of a program that I think is in many ways a model for others around the country. So I am pleased to welcome Roy and pleased to be here to hear from our other panelists.

Thank you.

Senator HUTCHISON. Well, thank you, Senator Sununu, for really making a point of not letting this hearing be delayed.

I am going to introduce all four of you and then ask you to speak in this order. I have no idea why the order is what it is. That is above my pay grade, but I am going to read my script.

Dr. Peter Voorhees is the Engelhart Professor and Chair of the Department of Materials Science and Engineering at Northwestern University. Dr. James Pawelczyk is an associate professor at Pennsylvania State University. Dr. Torbert, as has been mentioned, is Director of the Space Science Center at the University of New Hampshire. General Charles Bolden has the distinction of being an astronaut. He was a pilot on the trip that was taken by my colleague, Senator Nelson, and Senator Nelson asked for you to be a witness today. We are very pleased. After you left NASA, you went to the Marine Corps and served capably in the Marine Corps before retirement, and you have just been inducted into the Astronaut Hall of Fame. So we are very pleased that all of you are here.

I want to mention that there were two specific people we asked to be here who could not, but who are submitting for the record their testimony. Dr. Mark Lewis, the Chief Scientist of the U.S. Air Force. I asked him to talk about the cooperative role in aeronautics research that NASA and the Department of Defense through the Air Force could utilize. And John Karas, the Vice President for Space Exploration of Lockheed Martin Space Systems. They will provide written testimony.

So with that, let me start with you, Dr. Voorhees.

STATEMENT OF DR. PETER W. VOORHEES, CHAIR, DEPARTMENT OF MATERIALS SCIENCE AND ENGINEERING, NORTHWESTERN UNIVERSITY

Dr. VOORHEES. Thank you very much. Chairwoman Hutchison, Ranking Member Nelson, and Members of the Committee, thank you for inviting me to testify today. My name is Peter Voorhees. I am the Frank C. Engelhart Professor and Chair of the Department of Materials Science and Engineering at Northwestern University. I was a member of the National Research Council Space Studies Board and Chair of the Committee of Microgravity Research. Through my tenure as Chair, I have become familiar with the microgravity program and many of the areas within the physical sciences that are at the core of NASA's human exploration effort.

The future of research at NASA is being threatened as never before. I believe that a strong physical sciences research program is crucial to both capitalizing on NASA's significant investment in the area and to enabling the human spaceflight program. Only by supporting an ongoing physical sciences research program will NASA be able to avoid failures, that could have been anticipated by physical sciences research, and implement the President's vision for human spaceflight in the most cost-effective and rapid fashion.

The rationale for continuing physical sciences research at NASA lies in both the past and the future. Since 1990, NASA has been investing significant resources, measured in billions of dollars, in developing and maintaining a community of researchers in the microgravity sciences area. In 2003, the National Research Council study, Assessment of the Directions in Microgravity and Physical Sciences Research, found the quality of the investigators in the program to be excellent, and the research has impacted the fields in which it was a part. Ending the physical sciences research program will deprive the Nation of important discoveries in fields ranging from wetting and spreading dynamics of fluids on surfaces to relativity and precision clocks and negatively impact the ability to perform high quality research on the International Space Station.

Just as important as this past investment is the profound impact that physical sciences research can have on the future of NASA's human exploration effort. This is because important technology required for space exploration is affected by gravitationally related phenomena that are poorly understood. This lack of understanding hampers the design of a vast array of devices such as those for heat transfer, the prevention and detection of fires, fluid handling, and materials repair such as brazing and welding, among many others.

An example of the importance of physical sciences research is illustrated by the need to prevent and detect fires in a reduced gravity environment. We have had thousands of years of experience detecting and fighting fires on Earth. In contrast, our experience with combustion phenomena and microgravity or partial Earth's gravity is limited to, at most, 50 years. As a result, our understanding of flame propagation issues that impact spacecraft safety is very limited. It is, thus, not surprising that research in this area continues to uncover new and unexpected results. Although fires on the spacecraft are an unlikely event, if one should occur, it could be catastrophic not only for the mission, but for the entire human exploration of space effort. Given our lack of understanding of how fires behave in reduced gravity environments and the crucial importance of this to the human exploration effort, I can think of few stronger rationales for a vigorous combustion research program.

There are numerous other examples of the importance of physical sciences research in the human exploration of space effort as well.

In order to capitalize on the past investment and to ensure a future for the human exploration effort, it is crucial to retrain a broad spectrum of physical sciences research at NASA. The importance of continuity in a research program cannot be overemphasized. Continued support of this community is essential in engaging the best researchers, producing the students interested in working with NASA upon graduation, and performing the ground-breaking research that is essential to accomplishing NASA's human spaceflight goals. The level of support needed to continue funding a cadre of 250 investigators, which is the minimum number needed for a viable program, is quite modest compared to that formerly invested in the Office of Biological and Physical Research. Many investigators have recently had their programs terminated. If this support is not made available in the very near future, these scientists will be reluctant to return to microgravity research and the remaining researchers will also likely leave the program.

It is important to realize that funding physical sciences research will not diminish in any way NASA's future plans for human exploration. Rather, it will be an essential enabler of this effort. Finally, continuation of funding will allow NASA to reap the benefits of many years of funding high-impact research that is focused on gravitationally related phenomena.

Thank you very much for the opportunity to testify today, and I look forward to responding to your questions.

[The prepared statement of Dr. Voorhees follows:]

PREPARED STATEMENT OF DR. PETER W. VOORHEES, CHAIR, DEPARTMENT OF MATERIALS SCIENCE AND ENGINEERING, NORTHWESTERN UNIVERSITY

Introduction

Chairwoman Hutchison, Ranking Member Nelson, and members of the Committee, thank you for inviting me to testify today. My name is Peter Voorhees. I am the Frank C. Engelhart Professor and Chair of the Department of Materials Science and Engineering at Northwestern University. I was a member of the National Research Council Space Studies Board and Chair of the Committee for Microgravity Research. Through my tenure as Chair I have become familiar with the microgravity program and many of the areas within the physical sciences that are at the core of NASA's human exploration effort.

I believe that a strong physical sciences research program is crucial to both capitalizing on NASA's significant past investment in this area and to enabling the human spaceflight program. In 2004 President Bush provided a clear vision for NASA's human spaceflight effort and NASA has fully embraced the goal of returning humans to the Moon and eventually sending humans to Mars. However, to accomplish these goals research in the physical sciences is necessary to gain a more complete understanding of effects of microgravity on a wide range of processes as well as develop a variety of technologies to ensure the safety and success of these missions. Only by supporting an ongoing physical sciences research program will NASA be able to avoid failures that could have been anticipated by an ongoing physical sciences research program, and to implement the President's vision in the most cost-effective and rapid fashion.

The Development of the Physical Sciences Research Program

The evolution of NASA's physical sciences research program provides important lessons for how to formulate a successful research program to enable human space exploration. NASA's physical sciences research program began as the materials processing in space effort during the Skylab era. The program was singularly focused on performing experiments in space. As a result, many of the experiments were ill-conceived and few yielded new insights into the physical phenomena that were operative in space or impacted their respective scientific communities. In the early 1990s a new paradigm for research was initiated in the fluids, materials, combustion and fundamental physics research areas. In order to attract the best researchers, a concentrated out-reach effort was undertaken and a rigorous peer review system was instituted. In addition, a large ground-based research program was created that ensured that ideas were refined and scientific questions identified that could be answered only through space flight experiments. As a result the "shoot and look" approach to performing experiments during the Skylab era was replaced by carefully conceived hypothesis driven experiments. At its peak there were approximately 500 investigators in the program and it supported 1,700 research students.

The 2003 National Research Council (NRC) study "Assessment of the Directions in Microgravity and Physical Sciences Research" found the quality of the investigators in the program to be excellent. On the basis of an analysis of the citations of the papers published, prominence of journals in which the papers appeared, the influence of the research on the content of textbooks, documented influence on industry and the quality of the investigators in the program, we found that the microgravity program has had a significant impact on the fields of which it was a part. For example, 37 members of the fluids program were fellows of the American Physical Society, the materials science program produced some of the most highly cited papers in the area of solidification and crystal growth, and the fundamental physics program was funding six Nobel laureates. Many billions of dollars were invested in creating this successful and influential program.

NASA should take great pride in the creation of this high quality physical sciences research program in the fluids, combustion, materials and fundamental physics areas. It evolved into one of the jewels in NASA's crown. With the growth in the quality of the program, NASA became the primary source of funding for research in areas such as crystal growth, low temperature physics, and low Reynolds number and interfacial fluid flow, making NASA stewards of these important and broad scientific areas.

In early 2001 it became apparent that the International Space Station (ISS) program was facing major cost overruns. These financial constraints led to a major reduction in the microgravity research that had been planned for the ISS. Many of the experimental facilities that were planned were either reduced in size or delayed and the number of crew aboard the ISS was cut, making it difficult to perform experiments during the construction phase of the project. As a result, flight experiments were delayed or effectively canceled. The catastrophic loss of the *Columbia* orbiter in 2003 placed even more severe restrictions on the ability to transport samples and experimental equipment to and from the ISS.

The challenges posed by these recent events, the need to retire the Shuttle by 2010, as well as develop the Crew Exploration Vehicle have placed great pressures on NASA's budget. These financial constraints have resulted in a major reduction in the size and scope of the physical sciences research program. For example, with breathtaking speed and no external input, NASA eliminated the Office of Biological and Physical Research, and the Physical Sciences division within the office. The number of principal investigators has been reduced to less than 100 with still more reductions proposed. NASA's physical sciences research effort is on the verge of elimination. FY07 is the last chance to keep physical sciences research at NASA alive.

Rationales for Physical Sciences Research at NASA

The *raison d'être* for physical sciences research at NASA lies in both the past and future. Since 1990 NASA has been investing significant resources, measured in the billions of dollars, in developing and maintaining a community of high quality researchers in the microgravity sciences arena. The focus of this research is to use the microgravity environment to study a broad range of physical phenomena. The research spans from the basic to the applied, and will continue to impact both the scientific communities, of which the research is a part, as well as industry. As a result of the rigorous peer review of this research, important discoveries have been made in fields ranging from the wetting and spreading dynamics of fluids on surfaces to relativity and precision clock experiments. Moreover, many of the space flight experiments that flow from this program require the unique microgravity environment that is provided by the ISS and thus make use of a national asset that has been very costly to create. Ending the physical sciences research will squander the investment made in building the physical sciences research program and negatively impact the ability to perform high quality research on the ISS.

Just as important as this past investment is the likely impact of the physical sciences program on the future of NASA's human exploration effort. A vibrant physical sciences research program is the key to successfully accomplishing the President's Vision for Space Exploration, since important technology required for space exploration is controlled by gravitationally related phenomena that are poorly understood. This lack of understanding hampers the design of a vast array of devices such as those for heat transfer, the prevention and detection of fires, fluid handling, controlling the transport and movement of Lunar and Martian soils, and materials repair such as brazing and welding, among many others. The need for research in these areas is discussed in detail in the NRC report "Microgravity Research in Support of Technologies for the Human Exploration and Development of Space and Planetary Bodies." Given the central importance of these areas in fostering the human exploration of space effort, the impact of a physical sciences research program on one of NASA's central missions could thus be profound. As illustrations, I shall focus on two such examples: heat transfer systems and fire prevention and detection.

Thermal control is critical for spacecraft; excess heat must be rejected into space and moved from one section of the craft to another. In the past NASA relied on single-phase heat transfer systems, for example systems that involve only a liquid to transfer heat. However, there are clear advantages of employing systems that involve both a liquid and vapor (two phases), such as those used on the Earth. This allows one to employ the significant amount of heat required to transform a liquid to a vapor or a vapor to a liquid in the heat transfer process. This significant heat of vaporization or condensation allows the heat to be transferred in a far more efficient manner than with a single-phase system. The successful operation of such systems on the Earth frequently requires that the less dense vapor sit above the more dense liquid which, due to the presence of gravity, occurs naturally in a terrestrial environment. However this density driven stratification would not be present in space. This is but one of the many challenges of using such systems in space. Nevertheless, the advantages of using such a system in a spacecraft are significant. Given the enhanced efficiency, a multi-phase heat transfer system would save considerable space and mass. Heat pipes have also been proposed as possible heat transfer devices. These have the advantage of being completely passive where the motion of the fluid is driven by the surface tension of the liquid, but they also involve evaporation and condensation to transfer heat.

The central reason why heat transfer systems that involve multiphase flow are not more commonly used in spacecraft is that the dynamics of flow in systems with more than one phase, such as a vapor and liquid, in a microgravity or partial Earth's gravity environment are not well understood. A ground-based and flight program focused on the dynamics of flow in these multiphase systems could provide the insights to allow these higher efficiency devices to be used in the human spaceflight effort. While there are constraints on the mass and space available in the limited-duration environment of the Shuttle or ISS, the constraints placed on long-duration flights to Mars or even the Moon are even more stringent. Thus, the availability of high efficiency heat transfer devices, that occupy less space and have a smaller mass than existing devices, would open up much needed space for food and water. It is only through research in this area that these devices will be embraced by the spacecraft engineering community.

A second example of the importance of physical sciences research is in preventing and detecting fires in a reduced gravity environment. We have had thousands of years of experience detecting and fighting fires on Earth. In contrast our experience with combustion phenomena in microgravity or partial Earth's gravity is limited to at most fifty years. As a result, our understanding of the flame propagation issues that impact spacecraft safety is very limited, and research in this area continues to uncover new and unexpected results. For example, flames can spread along surfaces in the opposite direction to that on Earth, flames extend over electrical insulation 30 to 50 percent faster in microgravity than under normal conditions, and smoldering under microgravity conditions is less bright and more difficult to detect than on the ground. All of these results were determined from basic research conducted in only the past 10 years and have had a documented effect on the fire fighting procedures on spacecraft. Given the limited number of experiments performed in microgravity and the surprising results thus produced, there is much still to be learned.

Although fires on a spacecraft are an unlikely event, if one should occur it could be catastrophic not only for the mission but for the entire human exploration of space effort. The absence of any safe refuge on a spacecraft, and possibly lunar base, makes detecting and preventing small fires essential. Moreover, the design of lunar habitats that mitigate the effects of possible fires requires knowledge of how fires propagate in structures in partial Earth's gravity. Physics based simulation codes exist for fires in Earth-based structures, but none exist for micro or partial gravity environments. Given our lack of understanding of how fires behave in microgravity environments and the critical importance of this to the human exploration effort, I can think of few stronger rationales for a vigorous combustion research program. Such a program must involve an active ground-based program and, due to the long duration of many combustion experiments, ready access to the ISS may be required.

Going Forward

In order to leverage the past investment in physical sciences research and to ensure a successful future for the human exploration effort, it is crucial that a broad spectrum of physical sciences research in NASA be retained. The importance of continuity in a research program cannot be overemphasized. Continued support of this community is essential in engaging the best researchers, producing the students interested in working with NASA upon graduation, and performing the ground-breaking research that is essential to accomplishing NASA's human spaceflight goals. The level of support needed for this continuity is quite modest given that a cadre of 250 investigators, each of whom requires $130 thousand, would lead to a $32.5 million per year program, a very small investment compared to the $1 billion of the former Office of Biological and Physical Research. This represents the minimum support needed to keep a physical sciences research program alive at NASA. Many researchers have recently had their programs terminated. If this support is not made available in the very near future these scientists will be reluctant to return to microgravity research and the remaining researchers will also likely leave the program. As a result NASA will find itself in the same position as it was in the late 1980s: without an organized and influential microgravity research program. Unfortunately, NASA will never have the time or the resources to recreate a physical sciences research community. Therefore it is absolutely imperative that NASA fund physical sciences research at no less than $32.5 million for FY07.

To avoid many of the pitfalls of the past, it is essential that the program involves both ground-based research and spaceflight experiments. One of the crucial lessons of the early microgravity program is that only through the testing and refinement that is possible with ground-based theoretical and experimental research can experiments be performed in space that will yield reliable results. It is essential that both the ground-based and spaceflight research be rigorously-peer reviewed.

The future of research at NASA is being threatened as never before. It is important to realize that funding physical sciences research will not diminish in any way NASA's future plans for human exploration. Rather it will be an essential enabler in this effort. Finally, continuation of the funding will allow NASA to reap the benefits of many past years of funding of high impact research that is focused on gravitationally related phenomena.

Thank you very much for the opportunity to testify today. I look forward to responding to your questions.

Senator HUTCHISON. Thank you very much. That was very good. Dr. Pawelczyk.

STATEMENT OF JAMES A. PAWELCZYK, PH.D., ASSOCIATE PROFESSOR OF PHYSIOLOGY, KINESIOLOGY AND MEDICINE, THE PENNSYLVANIA STATE UNIVERSITY

Dr. PAWELCZYK. Madam Chairperson, members of the Committee, good afternoon. I thank you for the opportunity to discuss the impact of NASA's science cuts on the President's Vision for Space Exploration.

My comments are formulated from diverse perspectives. First of all, I am a former astronaut researcher and I flew on the Space Shuttle in 1998. Second, I have recently helped evaluate NASA's biological research for the Institute of Medicine and the National Research Council, as well as assess the progress of the National Space Biomedical Research Institute in Houston. Finally, I am a life scientist. I am a physiologist at Penn State, and my NASA research funded program was recently terminated more than a year in advance of our scheduled completion date. I am not bitter. Maybe a little.

The Vision for Space Exploration has caused dramatic change at NASA. Research that contributes to exploration goals takes precedence over experiments with intrinsic scientific importance and impact, and the entity responsible for funding such work, the former Office of Biological and Physical Research, has been absorbed into the Exploration Systems Mission Directorate.

Now, I agree with Mr. Griffin's view that aligning research with exploration goals is a good thing. However, naive or wholesale elimination of scientific themes is not. Funding for biological and physical research has declined almost 75 percent over a 2-year period, and this includes the cancellation of virtually all research equipment for the International Space Station that supports animals and plants, the elimination of 20 percent of the funding for external research grants, and the premature termination of 84 percent of these grants. Approximately 500 life science graduate students in 25 states are going to be affected by this.

Now, on a January interview with the Orlando Sentinel, Mr. Griffin was asked about the lessons learned from *Challenger* and *Columbia,* and he stated the following, "If you spend much time on this stuff and aviation accidents, a common theme is that of not listening to the signals the hardware is sending—the test results, the flight results, the dissenting opinions of the people involved. So a common theme is not listening. And I don't mean actively shutting out. I mean being so focused on what we're trying to do that we're not aware of what nature is telling us."

I think those insights are remarkably prophetic, and today I find myself before you as one of those dissenters. While I share Mr. Griffin's passion for the human exploration of space, my goal today is to ensure that you are, in fact, aware of what nature is telling us about humans in space.

Simply put, the biological risks associated with exploration class spaceflight are far from being mitigated. Musculoskeletal deconditioning remains of paramount concern. The rate of osteoporosis in astronauts today equals that of patients with spinal cord injury and it exceeds that seen in post-menopausal women by a factor of 10 or more.

Extrapolating from published studies of astronauts and cosmonauts, we can offer these preliminary estimates of the changes that would occur if humans made a 30-month trip to Mars starting today. Every single one of them would lose 15 percent of their bone mineral or more, and 80 percent would lose at least 25 percent of their bone mineral. More than 40 percent of them would lose greater than half of their bone mineral in their hip and in their femur, and that would set them up for catastrophic fracture. About 20 percent would lose more than a quarter of their exercise capacity, and approximately 40 percent would experience a decline in leg muscle strength of 30 percent or more. And these changes would occur despite the fact that astronauts are using the best countermeasures available currently. To my knowledge, no engineer would accept a spaceflight system where such degradation is expected, nor should it be so for astronauts.

NASA's Bioastronautics Roadmap is the comprehensive plan to document and reduce the biological risks of spaceflight, and in 2005, NASA's chief medical officer asked the Institute of Medicine to evaluate the road map. Despite the alarming data that I just described to you, we found a concern for these risks varied widely among astronauts, flight surgeons, and mid-level management. None of the 183 proposed risks mitigation strategies have been implemented for spaceflight and approximately two-thirds of these strategies were considered to be so incompletely developed that they would not be addressed further.

The problem is simply this. Biology has become the non-science at NASA. The Science Mission Directorate, which is the flagship, includes just four focus areas: astrophysics, Earth science, heliophysics, and planetary science. Biology does not appear at all. The next generations of space life scientists, who are the graduate students like my own, perceive a bitter lesson that is difficult to assuage. As a result of a shell game of agency-wide reorganization, life sciences are not recognized, valued, or funded adequately within science anymore. So to restore that scientific credibility, I think we need a coordinated strategy, and I'll offer you several recommendations.

First, add sufficient funding to the budget both to answer the questions essential for the vision and to replace the Space Shuttle in a timely fashion.

Second, articulate a time frame for delivering and completing a risk mitigation plan and vet that plan with the external scientific community.

Third, develop a comprehensive plan for conducting research on the International Space Station without the Space Shuttle. Include in that capability for six people or more and the logistics to keep them supplied.

And finally, establish sufficient oversight to hold NASA accountable to these goals.

Make no mistake about this. In the long term, we are retaining and accumulating human risk to spaceflight in order to progress with an underfunded Vision for Space Exploration. I think we have an ethical obligation to our current and future space explorers and to the American public to do better. Given sufficient resources, I remain optimistic that NASA can deliver the rigorous translational research program that the scientific community expects and the American people deserve, and I sincerely thank you for your vigilant support of our Nation's space program.

[The prepared statement of Dr. Pawelczyk follows:]

PREPARED STATEMENT OF JAMES A. PAWELCZYK, PH.D., ASSOCIATE PROFESSOR OF PHYSIOLOGY, KINESIOLOGY AND MEDICINE, THE PENNSYLVANIA STATE UNIVERSITY

Abstract—At the midpoint between the Apollo program and a human trip to Mars, NASA's recent reductions to scientific funding are unprecedented. In particular, the thoughtfully conceived architecture to explore the Moon, Mars and beyond has produced large reallocations of research funding that jeopardizes the stability and future of space life sciences. Given current budgets, NASA does not appear to have sufficient resources to fully engage the help of the external science community to complete the President's Vision for Space Exploration.

Madame Chairperson and members of the Committee:

Good afternoon. I thank you for the opportunity to discuss the changes NASA has made to its research funding. I have been a life sciences researcher for 20 years, competing successfully for the past 13 years for grants from NASA. From 1996–1998 I took leave from my academic position at The Pennsylvania State University to serve as a payload specialist astronaut, or guest researcher, on the STS–90 Neurolab Spacelab mission, which flew on the Space Shuttle *Columbia* in 1998. Since Neurolab I have had the privilege to serve as a member of NASA's Research Maximization and Prioritization (ReMAP) Taskforce. More recently I helped evaluate NASA's Bioastronautics Research Program for the Institute of Medicine, NASA's International Space Station Research Plan for the National Research Council, and the progress of the National Space Biomedical Research Institute (NSBRI).

During a January 19, 2006 interview with the *Orlando Sentinel,* Mr. Griffin shared his thoughts about his first 9 months in the position of NASA Administrator. When asked about the lessons learned from the *Challenger* and *Columbia* accidents, he stated the following:

> If you spend much time on this stuff and aviation accidents, a common theme is that of not listening to the signals the hardware is sending—the test results, the flight results, *the dissenting opinions of the people involved.* So a common theme is not listening. And I don't mean actively shutting out. I mean being so focused on what we're trying to do that *we're not aware of what nature is telling us* [emphasis added].

Those insights are remarkably prophetic, and today I find myself before you as one of those dissenters. I share Mr. Griffin's passion for the human exploration of space, but I must conclude with equal conviction that biological adaptation is a serious risk to an extended human presence in space, and that the scientific research necessary to ensure the health and safety of future astronaut crews beyond low-Earth orbit is far from complete.

ReMAP—Antecedent to the Vision for Space Exploration

For several years, NASA has recognized and responded to its need to complete necessary research in a fiscally responsible manner. In the spring and summer of

2002 NASA launched the Research Maximization and Prioritization Task Force, commonly known as ReMAP. Chaired by Rae Silver of Columbia University, the Task Force included two National Medal of Science awardees, one Nobel Prize winner, and more than a dozen members of the National Academy of Sciences, representing the breadth of translational research in the biological and physical sciences.

ReMAP was asked to prioritize 41 areas of research in the former Office of Biological and Physical Research. What was unique to ReMAP was our challenge to consider both the physical sciences and biological sciences simultaneously. This resulted in spirited debate and intellectual foment of the highest caliber. When we completed our task, highest priority was assigned to 13 areas that informed two broad, often overlapping, goals: One is the category of intrinsic scientific importance or impact; research that illuminates our place in the universe, but cannot be accomplished in a terrestrial environment. The other goal values research that enables long-term human exploration of space beyond low-Earth orbit, and develops effective countermeasures to mitigate the potentially damaging effects of long-term exposure to the space environment. It should be no surprise to you that over the past 17 years other review panels, both internal and external to NASA, have named similar goals.

The Task Force wrestled with the question whether one goal could be prioritized over the other. In the history of the United States space program both goals have been important, though their relative importance has changed over time. The limited amount of biological and physical research that occurred during early space exploration, particularly the Apollo era, focused on the health and safety of astronaut crews in a microgravity environment. Significant research questions that did not contribute directly to a successful Moon landing received lower priority. In contrast, more regular access to space provided by the space shuttle afforded an opportunity for "basic" research to take higher priority; the proliferation of space based research in the physical and biological sciences over the past twenty years is a testament to this fact.

Thus, the relative priority of these two goals of research—enabling long-term human exploration of space and answering questions of intrinsic scientific merit—has shifted during NASA's history. This conclusion is critical, as it suggests that one goal can receive higher priority over the other, though this ranking may change depending on NASA's definition of programmatic needs at a particular point in time.

When the President announced the Vision for Space Exploration in January of 2004, the relative balance between these two categories of research changed again. Items in NASA's research portfolio that most contributed to exploration goals would take precedence over experiments with intrinsic scientific importance and impact, and substantial realignment has occurred as a result. At the same time, the Office of Biological and Physical Research, the entity responsible for funding biological and physical research at NASA, was absorbed into the Exploration Systems Mission Directorate.

I share Mr. Griffin's view that aligning research with exploration goals is a good thing. However, naïve or wholesale elimination of scientific themes is not, and biological and physical research has certainly suffered from this effect. To the alarm of the scientific community, the process that began with ReMAP has taken a dangerous turn. Areas that we rated as highest priority, including those that contribute to exploration goals, have been de-scoped or eliminated completely.

Where is "Science" at NASA Today?

In many ways, the reorganization of "science" at NASA orphaned biology, and I encourage caution when you and your colleagues use the term in your discussions. Logically, "science" would seem an appropriate, generic label for research activities that occur throughout the agency. However, within NASA it appears to have a more specific meaning, often referring exclusively to the activities funded by the Science Mission Directorate, which includes the following disciplines only:

- Astrophysics—the study of matter and energy in outer space.
- Earth Science—the study of the origins and structure of our planet.
- Heliophysics—the study of planets, interplanetary space, and the sun.
- Planetary Science—the study of the origins, structure, and features of planets beyond our own.

Please note that the term, "biology," or the study of life, does not appear at all. To my more skeptical colleagues, the science of biology is disappearing at NASA.

The available evidence provides some support for this conclusion. While the Science Mission Directorate has suffered modest cuts, over the past 2 years, funding for biological and physical research (i.e., science *not* managed by the Science Mission Directorate) has decreased almost 75 percent, from $1,049 million in FY05 to $274 million in the FY07 Budget Summit. This includes the cancellation of virtually all research equipment for the International Space Station that supports animals and plants, the elimination of 20 percent of the funding for external research grants, and the premature termination of 84 percent of these grants. Approximately 500 life science graduate students in 25 states will be affected.

The next generations of space life scientists perceive a bitter lesson that is difficult to assuage: as the result of a shell game of agency-wide reorganization, life science is no longer recognized or valued within NASA.

Biological Research is Essential and Obligatory to the Vision for Space Exploration

I wholeheartedly endorse the President's goal to return humans to the Moon and Mars, but the current reductions in biological research funding appear sorely at odds with this goal. Simply put, the biological risks associated with exploration-class spaceflight are far from being mitigated.

This conclusion is based on analysis of 30 years of NASA-sponsored research. Since the days of Skylab, NASA-funded investigators conducted an aggressive and successful biological research program that was robust, comprehensive, and internationally recognized. Beginning with those early efforts, and continuing with our international partners on the *Mir* and the International Space Station, we have built a knowledge base that defines the rate at which humans adapt during spaceflight up to six-months duration, with four data points exceeding one-year duration.

Musculoskeletal deconditioning remains a paramount concern. In the past 2 years our ability to differentiate the trabecular bone network in the hip has helped us to appreciate that the risk to bone during spaceflight may be even greater than we previously anticipated. The rate of osteoporosis in astronauts equal patients with spinal cord injury, and exceeds that seen in post-menopausal women by a factor of 10 or more. Extrapolating from published studies of astronauts and cosmonauts spending up to 6 months in low-Earth orbit, we can offer preliminary estimates of the changes that would occur if humans made a 30-month trip to Mars today:

- 100 percent of crew members would lose more than 15 percent of their bone mineral in the femur and hip.
- Approximately 80 percent would lose more than 25 percent of their bone mineral.
- More than 40 percent would lose greater than 50 percent of their bone mineral.
- Approximately 20 percent would lose more than 25 percent of their exercise capacity.
- Approximately 40 percent would experience a decline in leg muscle strength of 30 percent or more.

Each of these predictions takes into account the fact that astronauts would be using the best countermeasures available currently! To my knowledge, no engineer would accept a spaceflight system where such degradation is expected. Nor should it be so for astronauts.

What is the Status of NASA's Human Biological Risk Mitigation Plan?

In 2005 NASA's Chief Medical Officer asked the Institute of Medicine to evaluate NASA's Bioastronautics Roadmap, the comprehensive plan to document and reduce the biological risks to human spaceflight. Despite the alarming data I just described to you, we found that concern for these risks varied widely among astronauts, flight surgeons, and mid-level management. None of the 183 proposed risk mitigation strategies had been implemented for spaceflight, and approximately two-thirds of these strategies were considered to be so incompletely developed that they would not be addressed further.

In his 2001 book, *Enlightened Experimentation: The New Imperative for Innovation,* Harvard Business professor Stefan Thomke offered the following four rules for enlightened experimentation: organize for rapid experimentation; fail early and often, but avoid mistakes; anticipate and exploit early information; and combine new and old technologies. While these principles are recognizable in NASA's Constellation System architecture, they are wholly absent in the implementation of NASA's Bioastronautics Roadmap.

We desperately need to increase human capabilities in space by translating findings from cell culture to reference organisms and mammalian models such as mice and rats to future flight crews. Translational research is the "gold standard" of the

NIH, and it is what the research community, and the American people, should expect from the International Space Station. We need the capability to house and test model organisms on the ISS. But equally important, we need adequate time for crew to prepare and conduct these experiments, and that time can be found only when the ISS moves beyond the core complete configuration. The potential return is immense; the application of this research to our aging public could become one of the most important justifications for an extended human presence in space.

Challenges for the Future

Earlier this year, Congress received The National Research Council's review of NASA's plans for the International Space Station, which identified several serious concerns about NASA's prioritization process for current and planned life and physical sciences research.

First, allocations to research did not appear to be based on risk, but convenience. Second, little emphasis was given to future lunar or Martian outposts, opting instead for short stays on the Moon. Third, the current ISS payload and the processes used to prioritize research areas appeared to be neither aligned with exploration mission needs nor sufficiently refined to evaluate individual experiments. Finally, no process was in place to plan or integrate future research needs that may not be recognized currently.

To restore scientific credibility at NASA, a coordinated strategy is necessary. I offer several recommendations for your consideration:

- First, add sufficient funding to NASA's budget, both to answer the questions essential to the Vision for Space Exploration and to replace the Space Shuttle in a timely fashion. An addition of $150 million would restore biological funding to the level of the President's FY06 budget request, but a minimal biological research program, directed primarily to external investigators, could be conducted with the addition of approximately $50 million/year.
- Second, articulate a time frame for delivering and completing a risk mitigation plan for humans exploring the Moon and Mars, and vet both the plan and the time frame with the external scientific community.
- Third, develop a comprehensive plan for conducting research on board the International Space Station without the space shuttle, including addition of essential equipment for animal research, deployment of a crew of at least six people, and logistics that are sufficient to keep these crews safe and supplied.
- Finally, establish sufficient oversight to hold NASA accountable to these goals.

Madame Chairperson, members of the Committee, make no mistake about this: in the long-term, we are retaining and accumulating human risk to spaceflight in order to progress with an under-funded Vision for Space Exploration. We have an ethical obligation to our current and future space explorers, and to the American public, to do better. Given sufficient resources, I remain optimistic that NASA can deliver the rigorous translational research program that the scientific community expects, and the American people deserve. I sincerely thank you for your vigilant support of the Nation's space program, and the opportunity to appear before you today.

Senator HUTCHISON. Thank you very much.
Dr. Torbert.

STATEMENT OF DR. ROY B. TORBERT, DIRECTOR, UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER

Dr. TORBERT. Madam Chair, Senator Sununu, Senator Nelson, I also want to thank you today for the opportunity to address important issues about NASA science. My name is Roy Torbert. I am a professor of physics at the University of New Hampshire and the Director of the Space Science Center, which participates in all the divisions of NASA science. I am now a lead investigator in a strategic mission for the Heliophysics Division: the Magnetospheric MultiScale Mission, or MMS. I have served as Dean of the College of Engineering and Physical Sciences, where the future of a technical workforce was my daily concern. I also serve on the NASA

Advisory Council Science Subcommittee for Heliophysics, although I do not speak for them today.

First, I would like to commend the American people, and you as their representatives, for their significant investment in NASA science. The United States has benefited a great deal from this investment. Not only is our technological base strengthened, but our competitiveness in the world and our educational investment in the future are greatly enhanced by NASA science leadership.

However, there is justifiable concern in the space science community today about future NASA funding. The Administrator has been forced to reduce the run-out for the Science Mission Directorate by some $3.1 billion to accommodate the requirements of the shuttle, the station, and the new Crew Exploration Vehicle, and even before the Fiscal Year 2007 budget proposals, NASA science had suffered a reduction. The request for the SMD in Fiscal Year 2007 is now less in real dollars than was appropriated in Fiscal Year 2004.

I make two points. First, the present budget has some significant impacts on NASA's ability to carry out its scientific program. And second, there are structural problems that drive up the cost of major science missions that are compounding our problem. Both of these conditions are severely limiting the frequency and variety of future NASA science missions.

Second, the immediate impacts. The NRC report, An Assessment of Balance in NASA's Science Programs, shows that many of NASA's programs have suffered even more than the overall budget numbers would imply. The Solar Terrestrial Probe, for example, within SMD now operates with about 75 percent of the funding that it had in 2004. As a result, the original 2010 launch of my program MMS has now slipped to 2013, and we find it very hard to recruit new students and engineers for a program whose launch date recedes faster than real time.

The NASA strategic planning process is stretching out the missing sequences of programs like Solar Terrestrial Probes by many years, but in doing so, the ability of key missions, STEREO, MMS, and the key ionospheric mission, GEC, to support each other have been compromised. In particular, the GEC mission has been deferred "indefinitely" beyond 2015. Indefinite postponement certainly forces many scientists to question the viability of their fields in the future.

In dealing with these impacts, NASA will preserve its strategic missions. The science community is worried about the extraordinary reductions in the smaller opportunities that form the basis for student involvement, and these include the Explorer, Discovery, and the Earth Pathfinders. They provide exciting science missions for a modest investment where students first learn the space science and engineering trade.

But the Explorer program has been cut back by half. There have been no Explorer AO's since 2003 and none expected for 2008. The Low Cost Access to Space program launch rate has been cut back by half. This year, in fact, it did not accept any remote launch site proposals. Even regular sites like the launch sites like Poker Flat are in danger by 2009. And the sustaining research and analysis budget has been cut back by 15 percent.

The NASA advisory subcommittees are now concerned about two findings of the NRC Balance report. I should mention that the first finding we accept, that NASA really is being required to do too much with too little at the present time. First, the balance between large and small missions is no longer optimal, and the cost to complete space and Earth science missions really needs to be scrutinized.

Why is it that the costs of major NASA and other space agency missions have grown far faster than technical inflation?

Most importantly, we simply do not have enough highly trained citizens to sustain our technical economy as the Gathering Storm report has made very clear. The retirement of baby boomers at NASA calls into question how we can sustain the Vision for Exploration over the long haul. I submit to you that the NASA science programs are a critical source of this needed native talent.

Two other factors are in my written testimony, the management of risk and the full cost accounting procedures at NASA.

NASA is a mission agency with exciting goals to accomplish, but it needs a sound technical basis, which is provided by the proper mix of supporting research and focused development. NASA should preserve programs that help train the next generation of space scientists and engineers. NASA should restore the vitality of the Explorer, Low Cost Access to Space, and the research and analysis programs, and we would like to ask the Congress, in considering the budget level for NASA as a whole, to give high priority to restoring funding for the space science enterprise as a whole.

Thank you.

[The prepared statement of Dr. Torbert follows:]

PREPARED STATEMENT OF DR. ROY B. TORBERT, DIRECTOR, UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER

Introduction

Madame Chair, Senator Sununu, Senators, I want to thank you for the opportunity today to address important issues that face the NASA science enterprise. My name is Roy Torbert. I am a professor of physics at the University of New Hampshire, and I represent the University as Director of the Space Science Center within the Institute for the Study of Earth, Oceans and Space. The Institute has 56 faculty who participate in nearly every division of the NASA science effort, as well as theoretical and ground activities supported by other state and Federal agencies, including NSF, NOAA, DOE, and DOD. The Institute presently supports 30 engineers, 57 graduate students, and over 70 undergraduates. I myself have served as principal investigator on several scientific instruments for NASA and am now a lead investigator in an upcoming strategic mission for the Heliophysics Division: the Magnetospheric MultiScale Mission, or MMS. I have also served the University as Dean of the College of Engineering and Physical Sciences, where the future of a technical workforce, an issue to which I will return, was a daily concern. Presently, I also serve on the NASA Advisory Council Science Subcommittee for Heliophysics. Although this committee has just been constituted and I cannot speak for the committee, I will address some of the issues that the committee has begun to consider.

First, and most importantly, I would like to commend the American people, and you as their representatives, for their significant investment in NASA science. Scientists like me know how difficult it has become to find funding for the many worthy causes that come before you, and we deeply appreciate your continued support. It is a signature achievement of our Nation that it finds the means and the will to look beyond the pressures of everyday concerns, to lift our horizons to explore questions about our place in the universe, our relations to our Sun and nearby planets, and how the Earth and its environment have functioned in the past and how they may fare in the future.

Of course, I also believe that the United States has benefited a great deal from this investment: not only is the technological base of our country strengthened by NASA innovations, but our prestige and competitiveness in the world and our educational investment in the future technical workforce are greatly enhanced by NASA science leadership.

The Space Science Budgetary Challenge

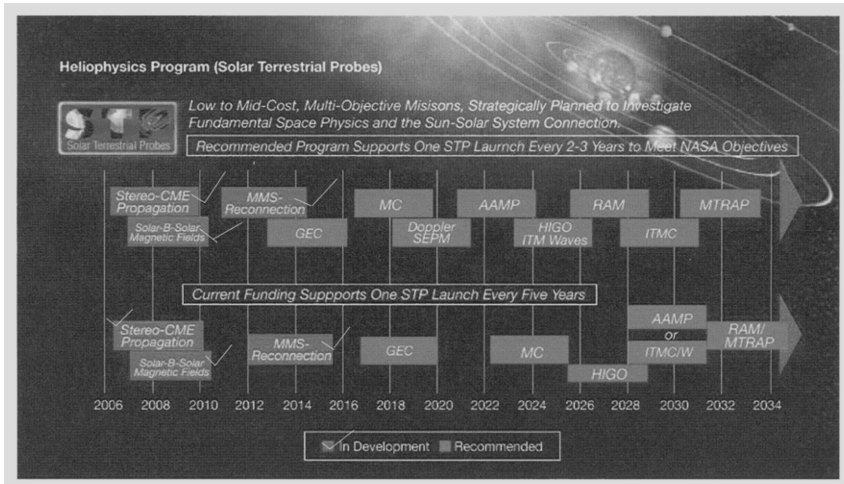
However, there is considerable anxiety in the space science community today about the future of science funding within NASA. In short, the Administrator has been forced to reduce the 5-year run out of the Science Mission Directorate (SMD) by some $ 3.1 billion to accommodate the requirements of returning the shuttle to flight status, to service the ISS, and to develop a new Crew Exploration Vehicle for service by 2014. The funding for SMD will therefore grow at only 1 percent real dollars over this period, and long-planned projects are being stretched out beyond the retirement age of many active scientists in the field. Even before these budgets were proposed for FY07, NASA science programs had sustained a reduction in scope. When the Vision for Exploration was first proposed in 2004, the SMD budget was $ 5.5 billion and projected to grow to $7 billion in FY08. The request for SMD in FY07 before you is now $5.33 billion, which is less in real dollars than was appropriated in 2004.

In this testimony, I would like to lay before you two main points. First, the present budget has some significant impacts on the ability of NASA to carry out its planned scientific program; and second, there are structural problems, namely, workforce issues, risk management approaches, and full-cost accounting mechanisms, that, by driving up the costs of major science missions, make these impacts even more severe. Both of these conditions are combining to severely limit the frequency and variety of science opportunities in the near future. First, let us consider the immediate impacts to our space science program.

Immediate Impacts in the Basic Space Science Mission

The budget numbers above would certainly require that NASA limit its plans for science. Some programs have suffered even more than these numbers imply. As an example, the Solar Terrestrial Probe line, within SMD, which supports the upcoming STEREO solar mission, and which will support MMS, now operates with about 75 percent of the funding projected in 2004. As a result, the 2010 launch date announced in 2004 for MMS has now slipped to 2013. It is very hard to recruit new students and engineers for a program whose launch date recedes faster than real time! As detailed in a recent, thorough report of the National Academy, entitled “An Assessment of Balance in NASA’s Science Programs,” many of the programs within other divisions, both within SMD and also within the Exploration Systems Mission Directorate (ESMD), such as microgravity life and physical sciences, have suffered even more severe reductions.

The science community, through the NASA strategic planning process, has been attempting to deal with these reductions in an orderly manner, by stretching out the development and launch plans when possible. Below are timelines for one such example of the Solar Terrestrial Probes, as extracted from the “2005–2035 Roadmap for Heliophysics” from the SMD roadmapping effort. The original sequence of missions in 2003, as diagrammed in the top panel, was thought to contain sufficient overlap in development so that complementary fields within the Heliophysics division of SMD, such as solar physics (STEREO mission), magnetospheric physics (MMS), and ionospheric physics (Geospace Electrodynamics Connections, GEC) could each contribute to the division goals of understanding the structure and dynamics of our solar system, its basic physical principles, and how the Sun influences the space and atmospheric environment around the Earth. The 2005 roadmap accepted the new budget realities, as outlined in the bottom panel, but now key missions have been stretched out. In particular, the GEC mission, which is the backbone of NASA research into ionospheric physics, has been deferred “indefinitely, beyond 2015.” “Indefinite postponement,” as a development timeline, certainly forces many scientists in the NASA enterprise to question the viability of their fields in the future.



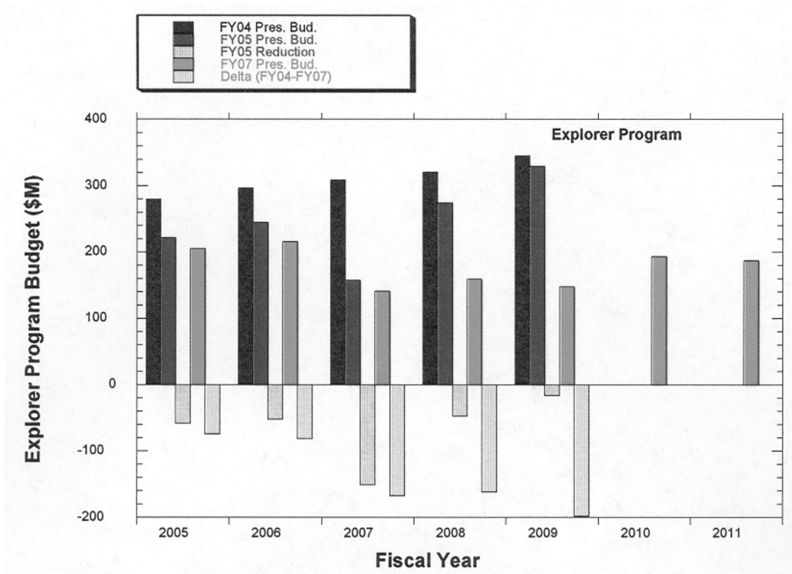
I must point out that these schedule realignments, as painful as they are, resulted from budget reductions prior to those proposed for 2007. The new actions forced on the Administrator, as outlined above, are just beginning to have their impact. It is appropriate that NASA, as primarily a mission agency, will adjust major mission schedules to preserve, as much as possible, its strategic vision.

What is causing considerable anxiety in the science community is the anticipated and extraordinary reductions in the smaller mission opportunities and sustaining research programs that form the support for much of the university-based research where students are involved. Small missions, such as those in the Explorer, Discovery, and Earth System Science Pathfinders programs, provide projects where new concepts are tested for a modest investment and where students first learn the space science and engineering trade.

This is particularly true of the Low Cost Access to Space (LCAS) effort that provides sounding rockets, balloons, and aircraft flight opportunities in a time line that falls within the educational program of a graduate student. Since 2000, the historical launch rate has dropped in half (from about 30 to 15 missions per year), with anticipated further reductions as a result of the 2006 budget. This year, NASA would not accept proposals for remote launch sites for sounding rockets, a critical capability for this program which often requires that the scientist and student teams launch their payloads directly into the specific region of space under study. The present run out budget places even the regular launch facilities, such as those at Poker Flat in Alaska, in danger by 2009.

The Explorer Program Is at Risk

The Explorer program (see *http://explorers.gsfc.nasa.gov/*) is another prime example of these impacts. Explorers are the original science missions of NASA, dating back to the very first satellite, Explorer I. They are universally recognized as the most successful science projects at NASA, providing insights into both the remotest part of our universe and the detailed dynamics of our local ionosphere. The Advanced Composition Explorer (ACE) now stands as our only sentinel to measure, *in-situ,* large mass ejections from the sun and the energetic particles that are a danger to humans in space. TRACE and RHESSI, study the dynamics of the solar surface where large solar storms originate, storms that often threaten satellites and other technological assets that we depend upon. Another Explorer, the Wilkinson Microwave Anisotropy Probe, continues to provide startling insights into the early structure of the Big Bang. Explorers are among the most competitive solicitations in NASA science, and offer opportunities for all comers to propose new and exciting ideas that are selected on the basis of science content, relation to overall NASA strategic goals, and feasibility of execution. The figure below details the budgetary prospects for Explorers. The FY07 proposed run out for Explorers will mean a program that is reduced by over half from its proposed FY04 guidelines.



In the 1990s, the Explorer program size mix was adjusted downward from the original "full Explorer" class to smaller satellites, labeled Medium-Explorers (MIDEX) and Small Explorers (SMEX). This was done to enhance the rate of new missions, in the face of limited funding and the cost growth of Explorers, a growth which had followed that of missions in general, an issue to which I will return. Even smaller, so-called "University Explorers" or UNEX, were also proposed but abandoned. For a number of years, this strategy allowed an Announcement of Opportunity (AO) every year, for either a single MIDEX or two SMEX class satellites. There has not been a single AO for Explorers since 2003 and the next possible opportunity is now 2008. That means there will be a 5-year gap in Explorer launches after the upcoming IBEX launch in 2008. Many university institutions have concluded that the years and dollars of up-front investment, necessary to put forward a successful proposal for the Explorer Program, can no longer be justified in the face of such limited prospects.

I would encourage the Congress to work with NASA to restore the vitality of both the Explorer and LCAS programs.

Concerns About the Research and Analysis (R&A) Budgets

A specific concern to university-based scientists is the impact on the sustaining Research and Analysis (R&A) budgets. The R&A program initiates many of the new, small scientific avenues that eventually lead to the major mission concepts that NASA pursues. They are highly competitive, maximize the science investment of ongoing missions by allowing all scientists to use available data, and are heavily weighted toward student and young faculty participation. These are moderate-term efforts, usually lasting three to four years, where new research and particularly theoretical approaches are explored. The Administrator has been forced by his budget realities to propose an immediate reduction of 15 percent in these programs. That may not seem catastrophic at first sight, but a sudden reduction in any long term program can have large effects. Because in any given year, approximately two thirds of the budget is already committed, next year the budget available for new grants must be reduced accordingly by 50 percent, on average. In some programs, it has been announced that it will be as much as 80 percent. If the budget were allowed to inflate, this rate would slowly recover in the next few years, but, with the present budget prospects, there is skepticism about its future. There is universal acceptance that these realities will inevitably reduce the number of new students who enter university programs like mine.

I have emphasized the budget impacts to programs with which I am associated, but nearly all science programs, both within SMD and Exploration Systems, are similarly affected, in some cases even more so. For example, the Earth Science division depends to a larger extent on the R&A program, and is therefore more severely reduced. The newly constituted NASA science advisory subcommittees will be forced to re-align strategic plans to available budgets and are beginning to study how the recently completed Roadmaps and the NRC Decadal Study plan can best be executed. Of particular concern are two findings of the above-mentioned NRC "Assessment of Balance" report (finding #'s 2 and 4): that the balance between large and small missions within NASA science activities is not optimal, and that the cost-to-complete of space and Earth science missions should be scrutinized. As shown here, much of the mission stretch-out in programs like STP and Explorers occurred even before the recent FY07 budget proposal, when the NASA Science Enterprise as a whole enjoyed budgets that were kept at least even with inflation, and sometimes even better. How much worse will it be if SMD must live with a declining inflation-adjusted budget?

I would encourage the Congress to augment the small mission and R&A effort in the NASA science budget.

What Are Factors Increasing the Costs of NASA Missions?

Why is it that the costs of the major NASA and other space agency missions have grown far faster than inflation? Or even technical inflation? I will offer three possible reasons, that all probably contribute, and some recommendations to address these problems.

First, it is clear that nearly all space projects require a great deal of technical competence, and a correspondingly competent workforce. There has been a steady erosion of that workforce, not only at NASA but across the entire country, and this fact has been decried from many quarters. The NRC report, "Rising Above the Gathering Storm," makes this case most energetically. Other technical industries have been able to compensate somewhat by tapping the pool of highly-trained immigrants and foreign students, and often outsource work abroad. As spacecraft are ITAR sensitive items, this pool is not available to NASA or to its outside space-enterprise partners, even to us at universities, because of the constraints of the law. All the space programs at NASA, DOE, NOAA, and the DOD feel this shortage acutely. And the situation will shortly be worse. NASA recently commissioned the NRC to study how the workforce necessary to carry out the Vision for Exploration can possibly be maintained, given the impending retirement of much technical talent with the baby boomers. I was invited to participate in that study where it became clear that the real shortage lies in the lack of engineers and scientists who had actually built, hands-on, space hardware and know how the hardware can be integrated and function within larger, more complex systems. I submit to you that the NASA science programs are a critical source of this needed native talent, whether they remain in NASA science programs or move out into the larger industrial base. Education at its very best is a process of discovery, of trial-and-error, and the efficacy of learning-by-doing has been proven over many years. NASA science is a natural partner for universities by providing a wide-array of opportunities for student participation where a mistake does not lead to a catastrophic loss of life or operational mission capability. I recently read a sobering article in Newsweek about students at MIT who opted out of the technical curriculum. They often cited a lack of excitement that could sustain them through a grueling educational program: it just wasn't "cool." For many, many students, NASA science provides the "coolness" factor. From robots on Mars, to solar storms, to questions about the origin of the Universe, NASA science is an exciting enterprise. In this light and in view of the key role of NASA science in the "Gathering Storm" report, it is unfortunate that NASA is not a component of the President's new "American Competitiveness Initiative." It is particularly discouraging that, at the critical moment when NASA science programs are needed most urgently by our educational institutions, we are forced to consider how to down-size their participation.

NASA needs to maintain its investment in space science programs that allow universities to attract and engage undergraduate and graduate students in all aspects of mission development and deployment—from proof of concepts studies, to proposal submittal, to prototype development, to launch, data analysis, and publication. Whether these programs have short or long time horizons, there are ways to allow the next generation of space scientists to participate in all aspects of an exciting NASA mission.

A second factor in the cost of science projects is the management of risk. Since the first Explorer I, NASA science projects have been extraordinarily successful. But over the years, the management procedures and quality assurance burden for science projects has grown to an almost unsustainable level, and has been driven to be commensurate more with manned missions, without any quantifiable impact in actually improving the final reliability of science missions, as far as many scientists can discern. I think the American people accept that the space business is risky, especially during launch and re-entry. Administrator Griffin has observed that, since 2 percent of these launches never achieve orbit, it makes no sense to spend hundreds of millions of dollars on procedures that might improve the reliability of payloads far beyond that, and I emphasize there is debate whether we are actually achieving more reliability. We have all learned that unnecessary risk in manned space programs has tragic consequences and clearly more must be done to minimize that risk. It is equally true that *not* taking risks in leading-edge science projects has undesirable results: not only must science continue to push the technological envelope where failure is a risk that accompanies new ideas, but these projects provide opportunities for training staff and students in an environment where failure is not life-threatening, where a student can gain hands-on experience in the real work of building state-of-the-art instrumentation, and, having gained this expertise, these students can go on to form the workforce of future operational and manned missions.

Now, no scientist likes the idea of failure. Not only are increasingly precious resources lost, and explanations to committees such as yours required, but even more importantly, many valuable years of all our team members, especially students, and even whole careers, are put at risk. With my university team, I have watched fifteen years of hard work vanish in the first few seconds of launch; in this case, a European launch. I can tell you that the silence that followed was agonizing. But that team picked itself up, worked with both NASA and ESA to rebuild those four satellites, and today this mission is on-orbit and returning remarkable results. Exploration, in its very nature, engages adversity, and it is the manner in which we overcome it that defines us as a nation.

I note that NASA SMD is presently undertaking a top-to-bottom review of the risk categories of its missions, and the processes that are appropriate for each class of mission. In that review, it is important that the "one-NASA" approach still allow a clear differentiation of different levels of missions, from manned shuttles and CEV's to very inexpensive sounding rockets. The scientific community applauds this effort, and wishes to work with the NASA centers to fashion procedures and processes that are appropriate to each of these levels, and that can be both cost effective and successful.

Third, and finally, there are some issues of accounting for costs that, quite frankly, are mystifying to the science community. NASA science centers have recently moved to a new accounting system, so-called Full Cost Accounting, which, on the surface, is a step forward, in that missions must account for all the costs associated with their full execution. Previously, there were center-based budgets, where the costs of maintaining needed expertise were carried in different accounts than the missions themselves. If these budgets were re-distributed to the mission budgets which then paid the costs, we would achieve more budget transparency. But, we cannot see where this distribution has been done. Furthermore, there is an inherent risk in this approach when the number of missions decreases, as seems to be the present case. If there is a certain amount of funding required to maintain center expertise, then a smaller number of missions must show higher required levels of funding to bear the fixed base costs, and therefore fewer missions and so on. The LCAS program stands in particular danger from this dilemma as the launch rate slowly dwindles. Taken to its ridiculous limit, pretty soon you have one single very expensive mission.

Summary

What is it that the science community is asking of NASA and this Congress? Through some serious work of the Advisory committees, we will be examining with NASA the balance of large and small programs. We realize that NASA is first-and-foremost a mission agency with exciting goals to accomplish. But these goals and missions cannot be accomplished without a sound technical and scientific basis which is provided by the proper mix of supporting research and focused development. We will be asking NASA to consider programs that help educate and train the next generation of space scientists and engineers. We will be asking NASA to evaluate the proper level of risk for science missions to allow science multiple opportunities to provide the technical progress and student training so that future manned and un-manned major missions can be reliably and affordably carried out. We would like to examine how the new center financial systems can be structured to provide faithful cost accounting in a manner that does not improperly burden science missions. And, we would ask the Congress, in considering the budget level for NASA, to give high priority to restoring funding for the science enterprise as a whole.

I thank you for this opportunity to discuss the budget implications for the NASA science program, one of our Nation's precious assets that we all want to nurture to an ever more inspiring and productive future.

Senator HUTCHISON. Thank you, Dr. Torbert.
General Bolden.

STATEMENT OF CHARLES F. BOLDEN, JR., MAJOR GENERAL, U.S. MARINE CORPS (RETIRED); CEO, JACKANDPANTHER, LLC

Mr. BOLDEN. Madam Chairman, Senator Nelson, Senator Sununu, I am honored to be afforded the opportunity to address you this afternoon on the very critical issue of budget and programs for the National Aeronautics and Space Administration.

As you have already mentioned, Madam Chairman, on my first flight, it was my honor to serve as a crew mate with a member of this subcommittee, Senator Bill Nelson, an experience that established a bond of friendship with him and his family, Grace, Nan Ellen, and Billy, that my family and I cherish to this day. Between my third and fourth flights on the Shuttle, I served as the Assistant Deputy Administrator of NASA here in Washington under then NASA Administrator Dan Goldin. My primary responsibilities involved spearheading a review of NASA's budget and its primary programs and projects and formulation of recommendations for program restructuring to fit within the budget constraints established by the Administration and the Congress of the United States. I left the space agency and active involvement in our space program in June 1994, so I feel that it is appropriate that I be classified as an outsider in offering my perspectives on the issues before this subcommittee.

NASA today finds itself faced with challenges of redefining and reorganizing in order to support and carry out the President's Space Exploration Initiative and enable us to maintain our scientific and technological leadership in the world while we progress in a timely manner in our efforts to return humans to the lunar surface and on to Mars. At this time, some of us are beginning to understand fully the statement credited to the late Dr. Bob Gilruth, who was Director of the Johnson Space Center in what may be called the golden age of human spaceflight, when he said "People will realize how difficult it was to go to the Moon when we try to return."

While we have a pretty good grasp on the technology to accomplish this mission, I am not certain we have the national will or determination to do it. I do not mean to insult anyone's intelligence here today, but I do wish to remind all of us that exploration of any sort is risky, expensive, and unpredictable. While we may be able to continue many of the science and exploration programs on which we have been embarked over the past 40-plus years, we cannot do them on the cheap and we cannot do them in series. Human exploration and science experimentation and research are necessarily parallel endeavors that are mutually supportive if we are to realize success in either.

From my perspective, you in the Congress and the President must see your way to expanding funding for NASA by some marginal amount that would enable Dr. Griffin to retain emphasis on many of the science and aeronautics programs that are being reduced or cut. As an example, building a vehicle or set of vehicles to take humans to the Moon and on to Mars, without continued emphasis on the life science research to understand more fully the environmental and human factors challenges that must be overcome to successfully allow humans to survive these journeys, is a certain recipe for disaster and ultimate failure.

Similarly, funding increased science exploration and experimentation through employment of robotic vehicles and remote sensing and satellite data-gathering, without continued improvement in our ability to safely send humans beyond Earth's bounds and on to other heavenly bodies, literally defeats our innate human drive and curiosity to explore the unknown and venture from this planet in search of ways to improve our lives here at home. In the very simplistic and perhaps somewhat naive words scribbled on a rough space exploration drawing by a young third grader in 1992, Samantha Aignier, "You'll never know unless you go." I think you all have a copy of Samantha's picture that I keep on my wall to remind me.

Perhaps the greatest casualty of NASA's failure to adequately fund a balanced program of human exploration and science and aeronautics research will be the continued deterioration in interest in science and math among our elementary and secondary school students, not to mention the college and post-graduate students who see no value in pursuing the fields of science and engineering where each year brings less and less funding for research to the university campuses. Where once students in elementary school responded with enthusiasm in large numbers that they wanted to be astronauts when they grow up, most no longer hold this aspiration when I visit the campuses around the United States to talk about my exploits as a test pilot and an astronaut. Many of today's students do not even know that we still have Americans in space every single day on the International Space Station. They want to know when we are going back into space and when are we going to the moon and on to Mars.

A closing thought on what I believe continues to be one of the greatest benefits of human space exploration, the incredible opportunity for international engagement and cooperation in a common goal. I feel that a primary reason that Russia exists today in relative peace and prosperity is due to the continued support and cooperation we gave to them from the days of the Apollo-Soyuz test project in 1975 through the fall of the Soviet Union, continuing on to today. We have an opportunity to forge the same kind of alliance with the people of China by fully welcoming them into the family of space-faring nations and opening opportunities to them to join with us in the peaceful human and robotic exploration of space. As is a common practice in our military, peaceful engagement with potential adversaries frequently makes them long-term partners in pursuit of the common goal of international peace and stability. Likewise in science and technology research, as well as human space exploration, engagement with our potential adversaries has the great advantage of focusing our efforts on common peaceful pursuits and advancing the cause of humankind here on Earth.

We already know how difficult it is to get humans safely into space and back home to Earth. We need not make it even more difficult by holding the NASA budget down to a level where we are forced to make the choice between scientific and technological research and human exploration, thus decreasing our chances of successfully pursuing either.

Thank you again for this opportunity to share some of my thoughts with you today. I too look forward to questions.

[The prepared statement of Mr. Bolden follows:]

PREPARED STATEMENT OF CHARLES F. BOLDEN JR., MAJOR GENERAL, U.S. MARINE CORPS (RETIRED); CEO, JACKANDPANTHER, LLC

Madam Chairman and distinguished Members of this Subcommittee: I am honored to be afforded the opportunity to address you this afternoon on the very critical issue of budget and programs for the National Aeronautics and Space Administration (NASA). A quick review of my background and qualifications to be here might be appropriate. I am a career officer of the United States Marine Corps, now retired after 34½ years of active service, 14 of which were spent assigned to the NASA Astronaut Office at the Lyndon B. Johnson Space Center in Houston, Texas as a pilot astronaut. At the time of my retirement, I was completing my service as Commanding General of the Third Marine Aircraft Wing headquartered at the Marine Corps Air Station Miramar, San Diego, California. During my tenure in the Astronaut Office, I flew four space shuttle missions—two as a shuttle pilot and two as mission commander. On my first flight it was my honor to serve as a crew mate with a Member of this Subcommittee, Senator Bill Nelson, an experience that established a bond of friendship with him and his family—Grace, Nan Ellen, and Billy—that my family and I cherish to this day. Between my third and fourth flights on the shuttle, I served as the Assistant Deputy Administrator of NASA here in Washington under then NASA Administrator, Dan Goldin. My primary responsibilities involved spearheading a review of NASA's budget and its primary programs and projects and formulation of recommendations for program restructuring to fit within the budget constraints established by the Administration and the Congress of the United States. I left the space agency and active involvement in our space program in June 1994, so I feel that it is appropriate that I be classified as an outsider in offering my perspectives on the issues before this Subcommittee.

As was the case in 1992 when I came to Washington to assist with Administrator Goldin's efforts to redefine and streamline the agency, NASA today finds itself faced with the challenges of redefining and reorganizing in order to support and carry out the President's Space Exploration Initiative and enable us to maintain our scientific and technological leadership in the world while we progress in a timely manner in our efforts to return humans to the lunar surface and on to Mars. At this time some of us are beginning to understand fully the statement credited to the late Dr. Bob Gilruth, Director of the Johnson Space Center in what may be called the golden age of human space flight, when he said "People will realize how difficult it was to go to the Moon when we try to return." While we have a pretty good grasp on the technology to accomplish this mission, I'm not certain we have the national will power or determination. I do not mean to insult anyone's intelligence today, but I do wish to remind all of us that exploration of any sort is risky, expensive, and unpredictable. While we may be able to continue many of the science and exploration programs on which we have been embarked over the past forty plus years, we cannot do them on the cheap and we cannot do them in series. Human exploration and science experimentation and research are necessarily parallel endeavors that are mutually supportive if we are to realize success in either. While the NASA Administrator, Dr. Mike Griffin, is making a very commendable effort to fit it all into today's NASA budget, it's like trying to fit fifteen pounds of stuff into a five pound sack. From my perspective, you in the Congress and the President must see your way to expanding the funding for NASA by some marginal amount that will enable Dr. Griffin to retain emphasis on many of the science and aeronautics programs that are being reduced or cut. As an example, building a vehicle or set of vehicles to take humans to the Moon and on to Mars without continued emphasis on the life science research to understand more fully the environmental and human factors challenges that must be overcome to successfully allow humans to survive these journeys is a certain recipe for disaster and ultimate failure. Similarly, funding increased science exploration and experimentation through employment of robotic vehicles and remote sensing and satellite data gathering without continued improvement in our ability to safely send humans beyond Earth's bounds and on to other heavenly bodies literally defeats our innate human drive and curiosity to explore the unknown and venture from this planet in search of ways to improve our lives here at home. In the very simplistic and perhaps somewhat naïve words scribbled on a rough space exploration drawing by a young third grader in 1992, Samantha Aignier, “We'll never know if we don't go!”

Perhaps the greatest casualty of NASA's failure to adequately fund a balanced program of human exploration and science and aeronautics research will be the continued deterioration in interest in science and math among our elementary and secondary school students, not to mention the college and post graduate students who see no value in pursuing the fields of science and engineering where each year brings less and less funding for research to the university campuses. Where once students in elementary school responded with enthusiasm in large numbers that they wanted to be astronauts when they grow up, most no longer hold this aspiration when I visit the campuses around the U.S. to talk about my exploits as a test pilot and astronaut. Many of today's students don't even know that we still have Americans in space every single day on the International Space Station. They want to know when we're going to return to space and go to the Moon and Mars.

I'd like to offer a closing thought on what I believe continues to be one of the greatest benefits of human space exploration—the incredible opportunity for international engagement and cooperation in a common goal of furthering our understanding of this universe in which we live. Experts site all kinds of reasons for the peaceful cooperation of Russia and the United States today, but I feel that a primary reason that Russia even exists today in relative peace and prosperity is due to the continued support and cooperation we gave to them from the days of the Apollo-Soyuz Test Project in 1975 through the fall of the Soviet Union continuing to today. We have an opportunity to forge the same kind of alliance with the people of China by fully welcoming them into the family of space-faring nations and opening opportunities to them to join with us in the peaceful human and robotic exploration of space. As is a common practice in our military, peaceful engagement with potential adversaries frequently makes them long-term partners in pursuit of the common goal of international peace and stability. Likewise in science and technology research as well as human space exploration, engagement with our potential adversaries has the great advantage of focusing our efforts on common, peaceful pursuits and advancing the cause of humankind here on Earth. We already know how difficult it is to get humans safely into space and back home to Earth. We needn't make it even more difficult by holding the NASA budget down to a level where we are forced to make the choice between scientific and technological research and human exploration thus decreasing our chances of successfully pursuing either.

Thank you again for this opportunity to share some of my thoughts with you today. Best wishes in your deliberations on the future of our national space program and the legacies it will leave to future generations.

Senator HUTCHISON. Thank you very much. I appreciate all of your viewpoints.

I want to start, Dr. Voorhees, with you. You suggest that the research in microgravity has matured substantially over the years, but now we may be in danger of losing that momentum. Could you lay out what would be the next step? What do you see out there in the near term that we may be missing because we are not pursuing what we can do in the International Space Station?

Dr. VOORHEES. I think there are so many things that we are going to be missing that it is difficult to contain them in a short answer to your question, but let me hit on some highlights.

There are questions in fundamental research that stretch from things such as how fluids behave in a microgravity environment. Experiments are going on right now, amazingly enough, even with all the challenges on the Station, looking at how colloids behave in space. These are models for crystallization of materials that are used on the ground. So we have this basic research effort underway on this that is underway in the microgravity program.

Senator HUTCHISON. Expand on that a little bit. What does a colloid crystal——

Dr. VOORHEES. OK. Imagine if you took a liquid and you disperse it and it is in very, very small particles, and these are particles that are smaller than the diameter of your hair, for the most part. In microgravity, you do not have to worry about these colloids settling down as you do on the ground. These colloids are marvelous models for the behavior of materials on the ground, how materials transform from a liquid to a solid. You start off with a random array of atoms in a liquid and it becomes a solid. The same sort of thing happens with colloidal crystals in space. So that is a very basic fundamental question that the microgravity program has been addressing.

But there are also issues that bear directly on the human exploration of space effort. I mentioned the combustion program. This is not just me saying that combustion is important. Every National Research Council study that has looked at the microgravity program in the past 10 years has recommended this is an important area to do research in. We simply do not understand how combustion works in a microgravity environment, and let me give you some examples.

If you were to start a fire on this piece of paper and you had a slow flow of air along the paper, on the ground the fire may burn in this direction. In microgravity, it burns in the other direction. So qualitatively different behavior in what you see in space and you see on the ground. And you would not know this unless you had the combustion research program underway within NASA.

The thing that we have found is that the NASA engineers are extremely interested in this information and very quickly incorporate this information into spaceflight safety procedures. But if you are not doing the research, you are never going to know.

Let me give you one other example. There is a very popular program that the National Institute of Standards and Technology makes, and it is a program that can be used to understand how fires propagate in buildings. It has been downloaded many thousands of times. If you were to ask NASA what happens in a fire on a lunar base, do you have a program that would simulate the evolution of the fire through this lunar base or through a spacecraft, the answer is it does not exist. And it is only through research in the combustion area that these programs can be developed.

So there is this enormous range of research underway from the very basic, which is the colloids, to the very applied, very closely related to human exploration and development in the space effort.

Senator HUTCHISON. One of the things that we put in the authorization bill that was new, in an effort to be creative on the money side, was to designate the U.S. portion of the Space Station a national laboratory. We did that because we thought perhaps there would be private sector research that would be beneficial to a company that could help pay for the cost of the Station and hopefully mitigate some of the reductions in funding from NASA that are not going into the research that we would all like to see.

This is open to anyone. Do you have any thoughts about how we could start pursuing those outside sources for the research in microgravity conditions that would stretch our dollars? We have public/private partnerships in NIH and ACI and there is no reason not to have it on the Space Station. Can you help us flush that out?

Dr. VOORHEES. I think the challenge of industrial research on the Station is the expense involved in transporting equipment and samples up to the Station and getting them back down. So that means for industries in general to do research on the Station, you have to find research that involves very lightweight materials, very lightweight experiments, and one that can be turned around relatively quickly, which is why some of the research that industry has been interested in, in the biological crystallization area, is a potential candidate for this.

The challenge of doing that kind of research like biological crystallization, for example, is the turnaround time and the difficulty of getting samples up and samples back and doing it quickly and on a timely basis. The time scale for biological crystallization research is very, very short, and so it has been difficult, I think, to engage many companies to become involved in that research. So I think it is a difficult thing to do actually.

On the other hand, I think designating the ISS as a national laboratory is a fantastic idea, one that I have been saying is exactly what we should be doing a long time because it is essentially a laboratory that allows people to do experiments in reduced gravity. That is what it really is and I think that is the way it should be looked at.

Senator HUTCHISON. Well, any other ideas on that subject? We are certainly looking for ways to maximize that designation and get some things going. So maybe if you think about it, you could provide written ideas later.

Senator Nelson.

Senator BILL NELSON. Well, I think the testimony from each of you has dramatically demonstrated why you cannot put 10 pounds of potatoes in a 5-pound sack and why we need to do each of the things that you have talked about: studies on the magnetosphere, Dr. Torbert; particles and how they behave in space, Dr. Voorhees; Dr. Pawelczyk, what is going to happen to the life sciences. Are the three of us, as former astronauts, going to mutate?

Dr. PAWELCZYK. Hopefully not.

[Laughter.]

Senator BILL NELSON. And, General Bolden, as that little girl said, you are not going to know unless you do it.

So all of this should come together. And that is what supposedly we have a science program in NASA for. That is why we have an International Space Station, which, by the way, I would like to see the Chinese involved with, General Bolden, as well. You were very accurate that as the thaw occurred between the United States and the Soviet Union, we already had this relationship in space that started way back at the time that we were mortal enemies, as two super powers. But here we have an International Space Station that we can do part of what you all are talking about and still keep the human dream and spirit and character of the American people alive, which is to explore the unknown.

So I am going to continue to agitate in what Senator Hutchison and I helped put together last year as a thoughtful approach to how NASA ought to be funded over the next 3 years. I will continue to agitate to try to fund to that level. Otherwise, you have the choices that are being made very painfully by Dr. Griffin.

Mr. BOLDEN. Senator Nelson, if I can say something. Because of where you come from, you understand the need for continued emphasis on space exploration from the standpoint of a technology workforce. It is the same thing in academics and in science and engineering. If we drive students and post-doctoral scholars away from the sciences and engineering because we do not have the money to fund it right now, you cannot turn it back on. It does not happen. Someone does not get a Ph.D. in weeks, and unless we maintain the interest in the life sciences and materials sciences and the other types of things that we have done both on the Shuttle and the International Space Station, we are going to find ourselves falling even more behind than many of us feel we are doing right now in terms of technological countries in the world. So for what it is worth.

Senator BILL NELSON. Yes, sir, Dr. Torbert.

Dr. TORBERT. Senator Nelson, I would like to add two points, both of which you mentioned there. One is this business about the ongoing programs for students, how you really cannot turn it off. I mentioned the GEC, which stands for the Geospace Electrodynamics Connection. This is a program in ionospheres which is really suffering. It is not a program I work in right now, but it is a classic case. There is a wonderful group at the University of Texas at Dallas, Senator, which has led the way in this research, which in fact suffers exactly this problem, that if opportunities do not come along that they can continue, then that whole line of research, that whole line of student interest may soon vanish.

The other one is that in science, as well as the manned program, the international aspect is really important. Science is an international effort. I myself have launched on a European spacecraft that ended up being launched on a Soviet launch vehicle. It was a wonderful experience and just like the manned program, it really is a way to foster peace, and it is an excellent program for the country to support.

Dr. VOORHEES. I would like to amplify on this issue as well because the microgravity program is an example of what happens when you do not put a program together carefully. If you look at the early pre-1990s microgravity program, the research that was done for the most part was rather ill-conceived and did not lead to very new and interesting science. In 1990, NASA decided to start building up this community, and it took about 10 years to do this. So if NASA was to cut the research now and not fund going forward, it will be another 10 years just to get back to where we are now.

Dr. PAWELCZYK. If I may pick up with that exact comment in the life sciences arena, I can assure you with the way that the ISS is designed at this point in time, we will never be able to do the research that we were able to do in the 1990s, and it is for the simple reason that we will have no capability to house or support research animals on board the International Space Station.

We talk about these issues such as bone research, and only within the past 2 years did we recognize what a mistake we had been making with that among Americans. Many of you have had bone scans, DEXA studies, and you get your rate of bone mineral loss. Well, that is sort of a lumped figure. We take a slice through a bone and we put the density of it all together. We now have the ability, only in the past 2 years, to compartmentalize that, look at the inside of bone versus outside of bone. What we have learned from astronauts is that the rate there is about 2.5 percent in that spongy trabecular bone. It is much, much greater than the outside part.

The only way we can look at that any further is to actually go in and sample that bone. We cannot do it in a human. We need a research animal to do that, and we do not have that capability, the capability that we did have when we were flying laboratories on the Shuttle.

Senator BILL NELSON. Well, you all have made my case very eloquently I might add. I would just add to what General Bolden has said, that we are here in a once-in-a-generation transition in human launch capability. You cannot delay this because the Shuttle is going to be shut down. We have a multi-billion dollar investment up there, the International Space Station, that we need to have the ability to get to with a sufficient crew so that we can do some of these experiments. So we have got to do this transition.

Now, how do you get it all done if you do not have enough money? And you do not. And that is the thesis of this whole thing. I think it is going to be incumbent upon us to go to work on this.

Madam Chairman, I would just say, as I would point out to everybody, that General Bolden has just been inducted last month into the Astronaut Hall of Fame. That is just like other halls of fame that you have heard about, the baseball, the football, and so forth. It is a distinct honor to be named to that. So my congratulations to General Bolden.

Mr. BOLDEN. Thank you, sir.

Senator HUTCHISON. Thank you.

Senator Sununu.

Senator SUNUNU. Thank you.

Dr. Torbert, you mentioned GEC. In your testimony you talk about the indefinite postponement and the message that that sends and the impact that it has on individual researchers looking at their chosen path, their chosen field.

Could you talk a little bit more about this type of situation and the impact it can have on recruiting? And in the particular case of GEC, what does happen to those researchers? Are there other opportunities that they can pursue? What might be typical for a situation where a mission is postponed for the individual researcher? Where might they end up?

Dr. TORBERT. Usually what happens in that case, this particular individual like in GEC is a tenured faculty member like myself, they will try to keep themselves entertained. That is usually what we went into science for. And they usually can. Some part of the research can continue. He is an individual about my age and so it is hard to teach older dogs newer tricks.

The real impact is that the line of students that he can recruit into that program, the line of students who may stay in space science or go into industry or go into the technological base, that line is stopped. Then the faculty look for different ways to invest their faculty resources, which are about our most precious level of resource.

So in that sense, over a long period, programs can accommodate. We will look for new areas of research. They may not be in the NASA area. I think that is a tragic loss. But they may go into different areas that—either physics or chemistry or whatever—they deem appropriate.

The real loss is that in this particular case, there are key questions of low-Earth orbit, ionospheric interaction with spacecraft, how the atmosphere interacts with the ionosphere with the sun and the input in the materials that we do put in the atmosphere and how that transports into the whole dynamics of that system. That whole line of thought is lost. Then it takes sometimes 50 years for somebody to say well, we did work on this 50 years ago. Let us try to remember what we did.

Senator SUNUNU. Are there any skill sets or areas of expertise where you are particularly concerned at this point in time, given where you see the budget is headed?

Dr. TORBERT. I would say the biggest impact—and I should mention I participated in an NRC panel that was invited by NASA to look for the future workforce in the Vision for Exploration. It was concluded in that panel that the key lack was scientists and engineers who had really performed hands on, built space instrumentation and knew how it functioned among larger systems. In that case, if you do not have those individuals, what we found—and this is a big driver, I think, in some of the cost of missions—you tend to overplan, overmanage. You tend to go through a whole period in which you do not know and have to train yourself instead of having gone through that procedure first and having gone through those mistakes.

I know when I was a graduate student, we had a very sensitive instrument, a detector, that we had to use, and it was always said by the graduate students you really were not a graduate student until you broke it. Like all the other graduate students, I said, well, that is not going to happen to me. I can tell you the look on my face when I went in to my faculty member and said, well, I just broke the equivalent of my entire year's salary. What are we going to do about this? Fortunately, I only broke it once, and that is the way that graduate students learn.

Exploration really challenges adversity, really challenges the limits, and we must train scientists and engineers to go through that process so that when we do plan big manned missions, big operational missions, we have people who know what they are doing. This is a critical part.

Senator SUNUNU. Dr. Voorhees, I want to ask you the same question. In your area of expertise and in your personal experience, is there a particular skill set that you are most concerned about given the projected changes in the science budget?

Dr. VOORHEES. I think the issue is engaging graduate students in the future. I have had this experience just recently in my laboratory with an experiment that was formerly canceled and now has been reenergized or refunded as a result of the 15 percent funding that has been given to the Station. I went in to one of my students and I said, well, it looks like we are going to be able to finally do the spaceflight experiment. She was just enamored. She was so excited about this. That excitement is what you lose when you do not have the funding that is connected with NASA.

A number of my students have worked with NASA engineers. A number of the students in this microgravity program have ended up at NASA field centers as scientists. That pipeline will entirely disappear if there is not the seed corn that is being put into the research program in the universities.

Senator SUNUNU. Dr. Torbert, it seems to me that we maximize that benefit, the inspiration, excitement, recruitment, when we are able to fund a variety of different types of investigations, a variety of different types of experiments that draw on different disciplines and different expertise. You mentioned in your testimony the value of the smaller mission opportunities. You mentioned Explorer, Discovery, and Pathfinder programs. Can you provide any other specific examples of smaller science missions and what you view their value and success to be?

Dr. TORBERT. I should not say just in our missions. There is the Wilkinson Microwave Anisotropy Probe I mentioned in my testimony. That is from the astrophysics side. There are planetary discoveries to asteroids. There are also planetary missions that may be even larger that do not come to the multi-billion level, such as Cassini and the former Galileo program. I also mentioned the sounding rocket program, and this goes across all the disciplines at NASA, the microgravity, also aircraft opportunities in the sounding rocket program, balloon programs. These are programs that come in the lifetime of a graduate student so that there is a particular ownership they take from designing the experiment, all the way through flying it, all the way through analyzing it.

Senator SUNUNU. I am sorry. What do you consider the life of a graduate student to be?

Dr. TORBERT. I will not talk about my life.

Senator SUNUNU. Is that 12 or 15 years or is that 3——

Dr. TORBERT. Hopefully not. We shoot for 4 to 5 years of a graduate student.

Senator SUNUNU. So a 4- to 5-year time frame. And what kind of an overall cost for these lower cost missions?

Dr. TORBERT. Well, a typical satellite mission, which is probably mid between those, usually will support three to four graduate students during that period, and with the NASA center costs and whatever, it comes to a couple of million dollars.

Senator SUNUNU. Which is extremely small compared to some of the larger missions.

Dr. TORBERT. We think we get a lot of bang for the buck.

Senator SUNUNU. General Bolden or Dr. Pawelczyk, do you have any thoughts about striking the right balance between bigger efforts, bigger scientific missions and some of these lower cost missions?

Dr. PAWELCZYK. Senator, I am not sure I would choose the bigger cost versus lower cost as the metric there, but I would try to think about scientific return. You have heard the theme here of graduate students as well. I would also think about that, projects that can fund large numbers of students and can continue to maintain technological excellence in the United States.

Let me give you a couple thoughts related to that. I think graduate students are the greatest virtue that I have working at a university. I refer to them as boundless enthusiasm unchecked by reality, and they teach me every day that they can do things that I never thought that they were able to do.

I also know, being at Penn State University, that we have a couple things that we value greatly. We value the longevity of our football coaches. We also value our land grant status, and we greatly value our space grant status as well in providing that. We have not even mentioned the space grant program here yet, which has also received enormous cuts and goes directly into funding students throughout each of the 50 States. As that program is scaled back, that is going to have an additional impact here that is really going to hurt us. We need to think about that one as well.

So I would really think about that student metric. I think you can quantify it pretty well. NASA has pretty good databases started on that. And you will see that effect right there. I see it every week when students come in and say I would love to work with you, and I say, I am sorry, but we have just lost our funding in that area and you are going to have to go somewhere else.

Senator SUNUNU. General?

Mr. BOLDEN. Senator, let me talk a little bit about my experience in the Marine Corps 9 years after leaving the space program. I was amazed at how much we use technology developed to support humans in space. Today when you send a Marine out with 150, sometimes 200 pounds on his or her back, you would like not to be able to do that. You would like to be able to give them a lot less stuff to pack but with the same capability. In some cases we can do that with communication systems, with, quote/unquote, guidance and navigation systems that have come through basic research, 6–1, 6–2 research.

I have sat on study boards for the National Academy looking at science and technology development for the Navy and the Marine Corps. One was called, "Navy Needs in Space," and it was amazing when you have people who tell you I do not need space, just give me my Classic Wizard and my GPS.

There is nothing that we do today in the military that does not rely on technology developed in space or for space. People talk about wasting money in space exploration. I have not seen a dime that we have spent in space to date. It all gets spent down here to develop systems that come about from the research that we do on orbit or just trying to get somewhere.

Sometimes we fail, but that also helps us determine a way not to do things. When you go back and look at electrophoresis operations in space that was the big thing—several staffers probably remember that. We were going to make very pure drugs because we were going to do it in microgravity. Well, it turned out that was not necessarily the best place to do it, but we were able to determine ways to change the process, to alter and perfect the process, so that it could be done much more cost effectively and much better here on Earth, but it was because of what we had found in doing that experimentation in space.

Like I said, space exploration is expensive, risky, and unpredictable. Frequently we come up with something serendipitously that we never, ever imagined, and it goes off to the military or it goes off to some laboratory or something.

But basic research has got to be done. It has got to be funded by DOD, by NASA, by somebody, and it is best done so that we get the most bang for the buck when it is done across the board. NASA is not the only government organization that is cutting back on funding for basic research today. We are not unique in that respect, and that does trouble me.

Senator SUNUNU. Well, I thank you. I want to close with one observation and one invitation.

The observation is certainly related to that last point. We have discussed and debated in this committee and in other committees in Congress the concept of a competitiveness initiative, and by and large, the core element of that has been increases in our funding for basic sciences. The chair and others have advocated for a greater emphasis on fundamental research, investment in the physical sciences through the National Science Foundation and other avenues. This science mission at NASA should obviously be part of that. To the best of my knowledge, it was not made a part of the Administration's competitiveness proposal, and I think that is something that we need to look at.

There have been a number of proposals related to competitiveness that I have not supported because they have not been sufficiently focused on basic sciences. But if we are going to do anything in this area, I think that the science elements within NASA and the science budgets within NASA ought to be part of that.

Finally, the invitation is to each of our panelists. Is there anything that you would like to offer that we have not been insightful enough to question you on?

Dr. PAWELCZYK. Let me just offer one area of research very briefly, and that is the area of fractional gravity. We have spoken a great deal about going to space and accessing space, but being in space provides us the opportunity to look at the range of gravitational fields that are less than what we experience here on Earth when we are in that free-fall environment and rotate something to induce the centrifugal field.

When I gave you the projections I did, I gave them to you assuming that the Martian environment would confer no safety to human bone or muscle or the cardiovascular system. That is the conservative estimate that I have to apply because I am worried about people like Charlie. I do not know if I am right or not.

What if that fractional environment does confer some benefit? Then a lot of these problems go away. We do not have to worry about whether or not we are going to need to rotate that Martian spacecraft to induce a gravitational field. Those are things in the structures that will be required to do that. We do not know those things, the answers to those questions right now, because we have not put that capability or we have removed that capability from the ISS, where storing fractional gravity research environments on the ISS is of extreme value for down the road, and it really is an investment in the future.

Dr. VOORHEES. You brought up the competitiveness initiative. In the microgravity sciences, the overlap between what gets done at NASA and in many other agencies is close but, nevertheless, distinct. So in this area, the ISS and access to these microgravity platforms is like going to a national laboratory, like taking a sample to a synchrotron, for example, an x-ray source. The same sort of basic research that is done in the microgravity sciences is very much related to the things that go in the other agencies in the competitive initiative.

Dr. TORBERT. One item that I mentioned I do think we need to work on ourselves. It is certainly the case that NASA desperately needs some remediation in the area of funding, but I mentioned the area of risk. I think this is important. You heard it in two aspects. You heard the fact that we take risks in doing exploration. That is an important thing. It is also important in science to have a variety of missions, and the more that we can fund, more inexpensive missions, reduce the cost of science missions, or as I pointed out in my testimony, differentiate the level of risk so that at the lower level we can take more risks. At the higher manned space level, of course, we have to be as risk-free as we can, but it is not absolutely risk-free. There is nothing risk-free about that endeavor. I think this is an important thing for NASA and its colleagues in universities to work together to do because if we can reduce the costs of these missions, then we can have more variety of them, we can take more chances, we can find some of those things out that we do not know, and this is an important contribution to the Nation's space program.

Senator SUNUNU. And do you think there is too great a level of discouraging risk at this point?

Dr. TORBERT. At present, most of the science community is discouraged by the level of risk mitigation. That is a natural thing. Let me tell you how it comes about. NASA tries to be, as I said, a "one-NASA" organization. There are very good processes and procedures that go throughout the program. And the good thing about it is there are managers and engineers who work with the manned space program, and then they come and work on various science programs. That way the NASA science personnel get a variety of experiences, which is all for the good.

But that has a sort of a diffusion tendency by which the procedure we had in this manned program can be applied to the sounding rocket program. Well, that is all good and true if you have those kind of resources, but we want more flights and to take the risk in the sounding rocket program which we cannot take in the manned program and everywhere in between. This is something we need to work on.

By the way, the SMD, the Science Mission Directorate, has just started a top-to-bottom review of its risk processes and we will be working very hard with that committee to see that we can fashion procedures that are both cost-effective and successful.

Senator HUTCHISON. Thank you. Thank you very much.

By the way, the concern you stated is one that I have, that NASA should be every bit as much a focus in the competitiveness initiative. We did try to push that along with cooperation agreements and requirements in the most recent bill that we passed on the competitiveness initiative, but I would love for you to look at it, if there are other things we can do. NASA has a uniqueness because of the Space Station and the microgravity conditions that no one else is going to have and fully utilize. So we do need to make sure that we are as committed to NASA and certainly the National Science Foundation in this competitiveness initiative as we can be.

Dr. Pawelczyk, you said that we are not using animals anymore and that has degraded the potential for the life sciences. Is the reason that we are not using animals because of funding cuts or is it because we are not putting the laboratory in the Space Station that would allow us to do that type of research?

Dr. PAWELCZYK. The answer is both of the above. So the facilities for housing animals on the International Space Station have been eliminated, the animal habitats. So they are not being funded anymore. They were approaching flight readiness.

If you look at then the constraining factors, assuming that were restored, there are sort of three different things that you have to balance and think about. You have to think about just getting stuff up there, how much mass you can actually take up on the shuttle with you, and we are sorely constrained on that now. It is a reason to encourage as rapid a development as possible of the cargo version of the crew exploration vehicle because it will provide a great deal of uncrewed up-mass.

We are also constrained by crew time. You are going to want people who are going to want to check in on these research animals as well, and that is part of the thing of getting to the six-person crew.

And then power is the last one as well.

When you look at all three of those, probably the most constraining factor is the up-mass, and that then also leads you to think more creatively about what can we do with our international partners in terms of looking at the autonomous transfer vehicle, for example, to bring up animals on board with that.

We will probably not be able to do all of the in-depth research, given the cancellation of things like the centrifuge accommodation module, but there is great value in simply having an animal up there for a long period of time and trying to look for the floor effect—to what point do some of these systems degrade—and then to using interventions like, for example, nutraceutical approaches. How can we modify with diet, for example, rates of bone loss and certainly pharmaceutical trials as well. So just having animals up there alone will provide some benefit.

Senator HUTCHISON. Thank you. That is very helpful.

As you know, in our Authorization Act of 2005, we did provide the necessity for NASA to give us a research plan for the International Space Station, and it is now on the website as of last week. Have any of you looked at that and is there anything that needs to be added to the body of knowledge that we have put forward today regarding that particular research plan, its inadequacies, anything else that you would want to focus on that it is not doing? Or, if there are good parts of it, tell us that as well.

Dr. PAWELCZYK. I have not reviewed the research plan at this point, but there is one key issue associated with any of these plans that I think is absolutely essential and that is the time frame at which it is done. We need clear milestones and simply saying we are going to push something to the right is no longer acceptable to us.

I will take the example back to the students. If I knew, for example, that there would be funding coming on board to mitigate these very important risks 5 years hence, well, I could at least begin to assemble with my life sciences colleagues ways to bridge that 5-year period. We would look at virtual classes, pooling across the Nation. And we do this very well with video technology now. We would look at ways to pool our resources to keep some nascent kernel going to that 5-year goal when we can then explode with that research opportunity. If we do not have that time frame, essentially it is out in the vapor. We do not know when it is going to happen. So a reliable time frame, something we can stick to, is essential.

Senator HUTCHISON. Any other comments on the scientific plan?

[No response.]

Senator HUTCHISON. My chief clerk says that we can distribute that plan to you as well, and if you do have comments, we would like to have them.

Well, thank you very much.

Senator BILL NELSON. Let me just make one concluding comment?

Senator HUTCHISON. Yes.

Senator BILL NELSON. I think there is a theme running through all of their testimony that the excitement generated by science and science research and spaceflight can do wondrous things for us for the future. Several of you have described it in terms of your students. We certainly saw this a generation ago when a President said we are going to the moon and return in 9 years, and that brought forth a whole new generation of engineers and scientists and mathematicians that, by the way, in the global context has kept us competitive in the global economic arena. That is the challenge for us in the future.

So I appreciate each of you bringing out that particular aspect in the importance of this little agency and what we are doing with this budget. I think it has enormous consequences.

Thank you, Madam Chairman.

Senator HUTCHISON. Thank you, Senator Nelson, and thank all of you for the time and the great information that you have given us today. We are committed on this subcommittee and certainly I think we have made great strides in focusing on the scientific basis that is the mission of NASA, and we will continue to pursue it. Thank you very much.

[Whereupon, at 3:50 p.m., the Subcommittee was adjourned.]

A P P E N D I X

PREPARED STATEMENT OF HON. TED STEVENS, U.S. SENATOR FROM ALASKA

I welcome our panel of witnesses today, who represent a range of interests in NASA programs, especially science and research at NASA.

I am well aware of widespread concerns being expressed that NASA is having to cut into valuable science and research programs in order to pay for building a replacement to the Space Shuttle as soon as possible, among other things needed to move forward with the Vision for Exploration.

I will urge this Committee to support the President's Vision for Exploration. And we support a strong commitment to a broad range of science at NASA.

NASA has always played an important role in maintaining America's technological and scientific excellence and enhancing our competitive position in the world.

The Competitiveness and Innovation bill recently reported by the Commerce Committee recognizes NASA's continuing importance and the need for maintaining a strong commitment to basic research.

The NASA Authorization Act of 2005, which was initiated by Senators Hutchison and Nelson, and which I was an original co-sponsor of, along with Senator Inouye, was signed into law last December. It provided a sufficient level of funding authority that would have avoided making most of the cuts in NASA science programs that we are hearing about today.

Unfortunately, the requested amount for NASA for FY 2007 is over a billion dollars less than we authorized.

We hope that additional moneys can be found to increase NASA's overall funding levels, and will continue efforts to make that happen, in working with our colleagues on the Appropriations Committee.

I hope that our witnesses today can help us explain why that additional funding is necessary, and how those additional funds would be used if they are made available by the Congress.

I thank the Subcommittee Chairman and Ranking Member for convening this hearing and look forward to hearing the panel of witnesses and reviewing other material to be submitted for the record.

PREPARED STATEMENT OF JOHN KARAS, VICE PRESIDENT, SPACE EXPLORATION, LOCKHEED MARTIN

Madam Chair and members of the Subcommittee, I would like to thank you for inviting me to provide Lockheed Martin's perspective for your hearing on the NASA Budget and Programs.

Lockheed Martin has interests in all of NASA's mission areas. We are excited about, and strongly support, the Nation's Vision for Space Exploration. We have a long successful history of providing spacecraft and mission operations support for NASA's Earth science and planetary exploration programs. We provide key systems for the Space Shuttle and International Space Station programs. And we depend on NASA's aeronautics research to design and develop systems for our military aircraft programs.

My statement today addresses U.S. leadership in space exploration and the following four issues:

1. The criticality of safe and timely return to flight of the Space Shuttle.
2. The imperative to utilize and effectively transition the skilled and dedicated workforce of the Shuttle program during the Shuttle phase-out by 2010.
3. The challenge of balancing priorities of space exploration, science, and aeronautics.
4. The importance of inspiring and educating the Nation's next generation of scientists, engineers, and explorers.

Safe and Timely Return to Flight of the Space Shuttle

Lockheed Martin is strongly committed to NASA's number one priority: return the Space Shuttle to flight and continue safe operation of the Nation's Human Spaceflight program. Lockheed Martin is a proud industrial partner with NASA on the Space Shuttle Program. As the contractor for the External Tank, we are acutely aware of the difficulties and challenges inherent in Human spaceflight. Our employees have worked hand-in-hand with NASA to create a safer external tank. As you know, the Gulf Coast region has been slow to recover from the devastating effects of Hurricane Katrina. Lockheed Martin has provided salary and other financial incentives to help retain employees in the Gulf Coast, and initiated a Hurricane Katrina relief fund comprised of corporate and employee contributions. We completed the Return to Flight II External Tank one week ahead of schedule, and have just barged the back-up External Tank (ET–118) to the Kennedy Space Center. We stand prepared to support the upcoming flight in July. I know I can speak for all of NASA's industrial partners when I say that we are all dedicated to fly the Space Shuttle safely until its retirement in 2010.

Effective Transition of Skilled Workforce

Workforce transition is the key to ensuring mission success while developing next generation systems and minimizing the gap in human spaceflight capabilities. NASA's Human Spaceflight Centers, with their talented and dedicated workforce, are the crown jewels of this country's Civil Space program. NASA is now addressing serious workforce and industrial base challenges to ensure successful execution of the Vision for Space Exploration. To compound the challenge, it is critical that during this transition, NASA and their industry contractors must also continue to safely fly the Shuttle and complete the International Space Station. A transition on the scale that NASA must undertake requires the combined efforts of local, state, and Federal Governments as well as industry if it is to be successful. It has been over 20 years since the United States has developed a new human spacecraft. The current skill mix—focused on Shuttle and Station operations—is not the same mix that is needed for development of a new system. Change is always traumatic, but it is within the crucible of change that innovation is born. There is precedence for such a transition. Lockheed Martin and the Air Force have retired the venerable Titan launch vehicle and several key spacecraft programs. Lockheed Martin successfully transitioned thousands of employees from these programs to other Lockheed Martin programs. During these transitions, we have worked closely with our customers to minimize contract termination liabilities; ensure supplier base continuity, including critical 2nd-tier suppliers; and ease the start-up of next generation systems.

Balancing Priorities of Space Exploration, Science, and Aeronautics

Since Lockheed Martin has interests in all of NASA's mission areas, any significant changes to NASA's budget allocations across their Mission Directorates impact our business base and earnings. However, we understand that we must join NASA in assessing the big picture, adjusting our strategic plans to reflect the Nation's most pressing Civil Space priorities. While it is important that we continue to aggressively pursue scientific discoveries in our solar system—deploying Earth science and weather satellites; autonomously searching for the origins, nature, and destiny of our universe; continuing the robotic search for life—it is also critical that the U.S. remain at the forefront of human space exploration. In fact, robotic scientific research and human exploration complement one another. As Dr. Griffin has succinctly stated, "the Vision for Space Exploration asserts that the proper goal of the Nation's space program is that of human *and* robotic exploration beyond low-Earth orbit." For example, current planetary orbiters and landers have applicable technologies for Human spaceflight. Administrator Griffin has admirably stepped up to these challenges and assumed responsibility for some very difficult decisions. Lockheed Martin strongly supports the Nation's Vision for Space Exploration, and we stand ready to help NASA overcome these challenges.

Inspiring and Educating the Next Generation of Scientists, Engineers, and Explorers

Finally, any discussion about the future of space exploration must focus on inspiring and educating the next generation of engineers, scientists, and explorers. It is our responsibility—in industry, at NASA, across academia, and throughout government—to make sure we are providing the opportunity and the motivation for our young people to enter careers of science, engineering, and mathematics. This is the only way the United States will remain a leader in developing the critical technologies to take us beyond low-Earth orbit, revitalize our Nation's industrial base, and guarantee a strong defense and national security. Lockheed Martin provides financial support to undergraduate engineering schools, and embraces a number of recruitment and mentoring programs to make certain that the talent pipeline stays full. To quote Lockheed Martin's CEO, Bob Stevens, "Talent is the critical resource that's going to drive success in the 21st century, period."

Thank you for the opportunity to provide my statement on this important topic. Lockheed Martin appreciates the Committee's interest in maintaining United States leadership in space exploration. We look forward to continuing to work closely with you on these important issues.

PREPARED STATEMENT OF MARK J. LEWIS, CHIEF SCIENTIST, U.S. AIR FORCE

On October 3, 1967, Major William "Pete" Knight set a piloted airplane speed record in the X–15A–2 rocket plane, flying at more than 4,500 miles per hour, over six-and-a-half times greater than the speed of sound. Nearly four decades later, this milestone accomplishment still holds the record for the fastest flight of a human being within a piloted aircraft. Pete Knight's flight was one of many great accomplishments in the X–15 program, which included over 199 flights beginning in 1959, and running through the decade of the 1960s.

The X–15 pioneered the air-space frontier, gathering valuable information that lead to the successful development of reentry and launch vehicles including the Space Shuttle. And it also represented one of many great aviation collaborations between the National Aeronautics and Space Agency and the United States Air Force.

Indeed, there is a time-honored tradition of cooperation between the civilian government aviation sector and military aeronautics research. The record of collaboration between NASA and the Air Force dates to the era of the National Advisory Committee for Aeronautics (NACA) and the U.S. Army Air Corps, the precursors of both today's NASA and our modern U.S. Air Force. In the 1920s, NACA performed landmark work on engine drag reduction, resulting in the so-called "NACA cowl" that greatly reduced the drag force on propeller-driven engines, and made possible economical airliners such as the DC–3 that catapulted American aviation to world dominance. Used successfully in civilian aircraft, including racing planes in the 1930s flown by one of my predecessors in the U.S. Air Force Chief Scientist's office, General James H. "Jimmy" Doolittle, the NACA cowl also greatly improved the performance of military aircraft in the years leading up to World War II. NACA's contribution to the military continued throughout the war, including solving problems such as tail buffeting and wing icing, improving the overall range and altitude of bombers, and increasing the speed of fighters by up to 50 mph by reducing unnecessary drag. NACA's contributions to military aviation performance were widely recognized outside the United States; the Battle of Britain was fought over London between German and British fighters that both used NACA-developed airfoils. When the superlative P–51 Mustang appeared in German skies in 1944–1945, Nazi military and scientific leaders marveled at its performance, made possible by NACA airfoil research applied to military fighter aircraft design.

After World War II, this fruitful civilian and military partnership in aviation continued. Then-Major Chuck Yeager's Bell X–1 flew beyond the speed of sound in October 1947 as part of a joint NACA–USAF cooperative program. Both organizations contributed their expertise to the development and flight testing of the X–1 series aircraft, and it is fitting that the prestigious Collier Trophy was awarded in 1947 to a team that included Yeager representing the USAF, NACA engineer John Stack, and the president of manufacturer Bell Aircraft, Lawrence D. Bell. In the years that followed, NACA contributed directly to the design of supersonic fighter jets for the Air Force and the Navy, developing the design principles that enabled routine penetration into the high-speed flight regime.

The intrinsic value of military and civilian cooperation was clearly recognized in the National Aeronautics and Space Act of 1958, which stated that the new agency's:

> "aeronautical and space activities . . . shall be conducted so as to contribute materially to . . . the making available to agencies directly concerned with national defense of discoveries that have military value or significance, and the furnishing by such agencies, to the civilian agency established to direct and control nonmilitary aeronautical and space activities, of information as to discoveries which have value or significance to that agency . . . "

The Space Act also mandated:

> ". . . close cooperation among all interested agencies of the United States in order to avoid unnecessary duplication of effort, facilities, and equipment."

In this spirit, cooperation with the Air Force continued once the Space Act was enacted and NASA was created from the various elements comprising the original NACA plus those from the Army's ballistic missile program. Whether in the use of military test pilots as the original astronauts or the application of NASA wind tunnels and materials to the design and development of high speed military interceptor aircraft, the Air Force and NASA have cooperated at all levels of their organizations. Today, there is not a single aircraft in service with the United States Air Force or, for that matter, any of our military branches, that does not benefit from NASA's aeronautical input. Recognizing the importance of continuing this legacy of shared cooperative achievement, leaders of both NASA and the Air Force have renewed their commitment to maintaining and strengthening cooperative ties between the organizations. This focus on cooperation leverages the capabilities of the two organizations, and though it is endorsed at the top-most levels it permeates the functional organizations and is ultimately enabled by numerous individual researchers.

Cooperation does not mean duplication, nor does it mean that either agency is performing the other's mission. Rather, it reflects the healthy relationship of two mature organizations that have strong specialties but who are, as well, united in a common purpose: ensuring continued American air and space dominance in the 21st century. The Air Force is responsible for system development, test and evaluation, and acquisition of military craft. NASA, on the other hand, has the mission of performing cutting-edge aeronautics research, leaving system development and acquisition to the civil aeronautics industry.

This fundamental difference means that, while NASA and the Air Force have similar levels of relative involvement in basic (fundamental) research, their respective roles diverge as activities move into the development arena. Since NASA also has responsibility for the operation and maintenance of numerous aeronautical test facilities, there is also opportunity for mutual cooperation in test and evaluation activities. Thus, while the missions of NASA and the Air Force are independent, their common research goals in aeronautics dictate a close research partnership that benefits both parties.

The original Space Act mandated that NASA has the responsibility for the "preservation of the role of the United States as a leader in aeronautical and space science and technology." Given that the military aeronautics revolution is now almost a century old, and the invention of the airplane already over a century, it is understandable that some may ask if a continued investment in aeronautical research and development is still relevant to NASA's mission, or for that matter, to that of the Air Force. After all, we have over a century of experience designing aircraft; what more is there to learn or do? Have airplanes really changed very much in recent history, and are they likely to change much more in the future? Have we solved the most important problems in aeronautical engineering, and are our analysis, design, and testing techniques as good as they will ever need to be? Along with such questions is one of overriding concern to the American taxpayer: should the resources originally dedicated to atmospheric flight be redirected to more promising research areas?

The answer to all of these questions, for the military, commercial and scientific sectors, is that aeronautics remains a vital and blossoming field of human endeavor. It is a discipline that is continuing to advance and develop, with great unanswered questions and incredible potential for future applications. Aeronautics continues to drive technology in other technical disciplines, ranging from computing to materials to energy utilization, and it remains an important part of our military capability as well as a key component for the continued exploration of space.

Some might adopt a view that aeronautics is "mature" because the rapid advances that characterized the opening decades of flight seem to overshadow more recent accomplishments in the field, at least under superficial inspection. Indeed, the 20th Century did see an increase in airplane speed from 10 mph of the original Wright Flyer to over 2,500 mph for the SR–71 Blackbird; an increase in altitudes from a few feet above the sand dunes of Kitty Hawk to the fringes of the atmosphere; and the introduction of such revolutionary technologies as jet engines, automatic flight controls, pressurized cabins, and regular passenger air transportation. The first century of aviation transformed our civilian world and ushered in a new era of military effectiveness with hitherto undreamed-of capabilities made possible by air power. Such capabilities as stealth technology and unmanned systems are among the most recent of these successes. We can be certain that advances in this second century of aviation may be less *overtly* spectacular, but ultimately will be no less spectacular in the fundamental and profound impacts they will have on both the commercial and military sectors.

Several important trends are apparent as we look at aviation progress in the decades to come:

1. Aerospace engineers will continue to push the boundaries of aircraft height, speed, and performance. Automation and unmanned systems will play an ever-increasing role in air power, building on the success of Predator and the Globalhawk unmanned aircraft. Technologies will be developed that will allow us to operate at higher altitudes for more persistence and permit us to fly at very high speeds to strike fleeting targets rapidly and accurately. As closing the "sensor to shooter" loop has enhanced our ability to detect and fire upon a foe, closing the "shooter to target" loop with high-speed weapons will further degrade the ability of any foe to act against us. This might be a cruise missile able to accurately reach targets 1,000 miles away within mere minutes, or a supersonic-cruising UCAV dispensing advanced penetrating smart munitions. This same technology may allow us to use an airplane-like operational model to reduce the cost of launching spacecraft into Earth orbit and provide unprecedented access to the space environment.

2. Aeronautics will continue to play a key role in the development of space technology for both the Air Force and NASA. Space vehicles are subject to significant aerodynamic forces during launch and reentry. In the modern era, air and space vehicles are *inter*dependent, not independent. Each is critically dependent upon a robust understanding of the other. This is an area for continuing aeronautics research, and the general topic of flow over reentering surfaces will be of great importance in the development of future manned and unmanned spacecraft, including NASA's planned return to the Moon and visits to Mars. In fact, at this very moment, engineers from NASA's Langley Research Center are working with an Air Force team to test a heat shield for the Mars Science Laboratory in the Air Force's Hypervelocity Wind Tunnel in White Oak, Maryland, just a few miles north of Washington, D.C. In the fall, this same NASA-Air Force team will begin testing designs for NASA's manned Crew Return Vehicle, the craft that will bring astronauts home from the next series of lunar missions.

3. Fuel costs and availability, as well as environmental and operational concerns, will also drive another important aviation research push: greater fuel efficiency and use of non-traditional energy sources. To further increase efficiency and improve performance, the tremendous advances in material science and computers will enable us to build and fly aircraft that can change their shapes in flight.

In each of these areas, engineers at NASA and the USAF are bringing their unique capabilities, resources, and mission perspectives to the challenges at hand, for the good of our Nation. These cooperative efforts span the range from formal, executive-level committees to informal technical exchanges between individual researchers; and cut across programs, projects, personnel, test facilities, and infrastructure.

Three principal mechanisms describe the nature of Air Force and NASA cooperation:

- *Strategic Partnerships* are defined as cooperative arrangements where each organization shares program goals at the highest level consistent with national policy. High-level, long-term agreements are currently in place ensuring that Air Force's and NASA's unique capabilities are closely coordinated. This close coordination of strategic goals and objectives supports long-term mission planning, provides a significant reduction in potential duplication of effort, and supports the potential identification of specific cooperative initiatives.
- Cooperation and collaboration in areas of *Mutual Technology Interest* encompass scenarios where the agencies share common technology interests but not necessarily common programmatic end goals and are typically technology advancement oriented. In this type of cooperation, Air Force organizations and NASA leverage mutual interests in technology development to pool financial resources, add unique capabilities and/or expertise, and reduce risk by coordinating and sharing results from complementary RDT&E tasks and programs.
- The third mechanism for cooperation is *Transactional.* Here one organization "purchases" an expertise or resource from the other organization. In this scenario the providing agency does not necessarily have an interest in the activity being undertaken, only a specialized skill or resource, to include facilities, needed for that program.

A comprehensive list of each of the areas of NASA and Air Force cooperation would fill volumes. I will however highlight just a few of the exciting topics we are working on together.

1. As mentioned above, both NASA and the Air Force have a strong interest in high-speed flight, into the so-called "hypersonics" regime of Mach 5 and above. For the Air Force, this is a field that will enable high-speed weapons and eventually better access to space; for NASA, hypersonics is important for the design of reentry craft, as well as launch and eventual civil applications. A key flight test vehicle that will answer many of our questions regarding hypersonic flight is the Air Force's X–51, and we are drawing on NASA expertise to make this program a success. NASA has already flown its own hypersonic craft, the X–43A, which set a record for Mach 10 airplane flight in November 2004. But whereas the Air Force's X–51 would have application primarily to weapons systems, the X–43A was a test of a civilian aircraft configuration, fitting well with NASA's mission. Drawing on knowledge that they gained in designing and flying the hypersonic X–43 aircraft, NASA has provided important and valued support to the X–51 program. Personnel from NASA's Langley Research Center have played a principal role in the X–51 design process, including propulsion, aerodynamics, and wind tunnel tests. In fact, because of the unavailability of Air Force facilities, the Langley Research Center has stepped in as the lead X–51 engine test site and has worked tirelessly since last November to ready one of their wind tunnels for that purpose.

2. NASA is also helping the Air Force with *FRESH–FX,* an experimental program on the fundamental physics of hypersonic flight. This activity will launch low-cost experiments on sounding rockets under joint funding with the Australian government. The product of this effort will be an "experimental flight laboratory" for the evaluation of numerous high-speed flight phenomena and aerospace systems technologies. The scope of this program will include the examination of basic phenomena deemed critical to the eventual development of hypersonic technologies; for example, chemical kinetics and combustion in airbreathing propulsion, aerodynamics, physics of surface flows and shock waves, high temperature effects, integrated adaptive guidance and control systems, sensors, materials and structures, and new instrumentation. An extensive NASA team reaching across five NASA Centers will provide technical guidance, computational support, and experimental validation and consultation. Our NASA partners will perform computational analysis and experimental validation, and will execute both aerodynamic and propulsion tests at NASA Langley, as they are doing now for X–51. Last, NASA personnel from Dryden and Wallops Island will support the flight activities with systems integration and launch operations.

3. Some of our collaborations are occurring in lower-speed regimes, but are no less exciting. One such effort is the *Morphing Wing* program, exploring airplanes that can change their shapes in flight to perform better over a wide range of mission objectives. Success in this area may one day produce a single aircraft capable of conducting attack, reconnaissance, and perhaps other types of missions. Rudimentary examples of morphing technology are flying today, including variable-sweep wings of the Navy's F–14 fighter and B–1B bomber, as well as the flaps located on the trailing edge of nearly all military and civilian aircraft wings. Compared to these current examples, future applications of this technology will seem light-years ahead, using so-called smart materials and advanced actuators to produce large-scale changes in shape and wing function. An airplane thus equipped could extend its wings for slow, loitering flight, then fold them up and reshape them for enhanced maneuverability and speed. The military applications are obvious, but much of the expertise to accomplish this resides with the engineers at NASA. And the results may eventually lead to better civilian aircraft as well.

4. A closely-related program in *Active Aeroelastic Wing* (AAW) technology is also bringing engineers from NASA and the Air Force together in a multidisciplinary technology that integrates aerodynamics, controls, and structures to maximize aircraft performance. This concept is actually a throwback to the very first airplane: rather than use ailerons or flaps to maneuver their Kitty Hawk Flyer, the Wright Brothers' employed twist or "warping" of the wingtips to control its motion. Like that first Wright Brothers' plane, the wings of today's high-speed aircraft also warp or twist at very high speeds. But unlike the Wright Brothers' plane, this high-speed warping is not deliberate, and usually has negative effects. The Air Force, in cooperation with NASA Dryden Flight Research Center and the Boeing Phantom Works, is studying a "wing warping" approach to control this twisting for a net benefit. Once this technology is transitioned to operational aircraft, it promises to significantly improve the high-speed roll maneuverability of the aircraft by actively controlling the wing shape.

These programs and more demonstrate the value of synergy between the U.S. Air Force and our colleagues at NASA. Today we are also working with NASA to apply airplane concepts that they developed for scientific missions, specifically long duration atmospheric sampling, to give us long-loitering high-altitude reconnaissance. Because of our keen interest in reducing fuel expenses and reliance on foreign fuel supplies, the Air Force is working with NASA to identify entirely new shapes for airplanes that will be more energy efficient. The result of these activities will be concepts for more fuel-efficient airplanes that will make for better long-haul airlines or long-range bombers. Concern about aircraft maintenance and combat readiness is leading to joint activities in sustainment, inspection, and repair. We are also working together across the board on the exploration of new materials for both military and commercial aircraft and spacecraft. Yet another important success story is that NASA and the Air Force are now working closely to coordinate our wind tunnel facilities. We want to prevent duplication but be certain that the Nation's aerodynamic testing needs are properly served.

Finally, I offer some observations regarding NASA's renewed commitment to inter-agency cooperation. Put simply, the Department of Defense, and the Air Force in particular, could not have a better partner than the present NASA leadership. When Administrator Michael Griffin arrived at NASA, he made it very clear that cooperation and interaction with the Department of Defense would be a high priority, and he has honored this commitment. Dr. Griffin and the Associate Administrator for Aeronautics, Dr. Lisa Porter, have been extremely enthusiastic about teaming with us and have built a strong working relationship. From the Air Force's view, Dr. Porter is rebuilding and revitalizing an aeronautics program at NASA that had sadly declined over many years. Their efforts are logically conceived and intelligently implemented, doing the sorts of things that NASA should be doing while recapturing the spark of excitement on the frontiers of aeronautics. Dr. Porter has been receptive toward including Department of Defense mission goals among the systems applications that NASA's foundational research efforts will enable. She has visited DOD facilities, included DOD experts in review panels, hosted DOD visitors to NASA, and encouraged NASA's workforce to seek expanded ties to their colleagues in the Pentagon and the service laboratories. To this end, we are in the process right now of ratifying a Memorandum of Understanding between the U.S. Air Force and NASA, to formalize and codify the close relationship that is already in place.

As we begin this second century of flight, the United States Air Force sees NASA as a valued, indeed critical, partner. Where our mission areas are synergistic, we want to pursue logical connections. As we expand upon this special relationship, the Air Force appreciates the important differences between NASA's mission and ours, as well as the special responsibilities that NASA has in preserving and continuing America's leadership in aeronautics. Our goal is not to subsume NASA under the DOD, nor redirect NASA's work to military-only activities. Rather, we seek mutual benefit and intelligent coordination to maximize the benefits of our Nation's investments in aeronautics. Together, we are greater than our sum.

Response to Written Questions Submitted by Hon. Kay Bailey Hutchison to Dr. Roy B. Torbert

Question 1. I was struck by several references in your statement to student interest and involvement in space sciences research. Would you agree that an important reason to consider sustaining this sort of research at NASA is to help meet the growing crisis in Science, Technology, Engineering and Mathematics education?

Answer. I believe that this is a major collateral benefit of the investment we make in NASA science. The availability of real experiences for students is an educational asset like no other.

Question 2. To what extent do you believe there are opportunities for cooperative research between NASA and NSF in the science disciplines with which you are familiar?

Answer. There are may cooperative efforts that are continually undertaken at present. NASA and NSF have an arrangement that divides the responsibilities between them, that has worked very well, but they continue to collaborate where it makes sense.

Question 3. In your written statement, you make reference to launch sites such as Poker Flats, run by the University of Alaska in Fairbanks, being threatened by cutbacks in small launch payloads. What kind of scientific research is represented by those payloads? Do they typically involve students and faculty in the experiments?

Answer. Poker Flat is the primary remote launch site for the sub-orbital rocket program that NASA manages out of Wallops Island (part of GSFC). It probably has the largest component of student research of any effort within NASA. Primarily they do upper atmospheric and ionospheric research.

Question 4. The Space Sciences portion of NASA's budget has steadily increased over the past fifteen years to now represent roughly 33 percent of NASA's total budget. The FY 2007 request slows that growth rate to 1.5 percent for FY 2007 and 1 percent per year after that. It appears from those facts that Space Science is not being "cut" but that the potential or previously-planned increase has been reduced. What do you believe the ideal ratio of space science funding should be for NASA in the future?

Answer. It is correct that the science portion per se has seen an increase over the last 5 years, but it is also correct that the number and diversity of space science projects has also dramatically decreased in the last 5 years, as I make clear in my written testimony. The science community is reacting to the huge loss of projects that have been planned for a long time. This is the conundrum of increased costs that I discussed. I believe that NASA and the science committees must really address this dilemma. It will affect even more the financial viability of the Vision for Exploration.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. KAY BAILEY HUTCHISON TO DR. PETER W. VOORHEES

Question 1. What are some of the physical science disciplines or areas of research that have the highest potential for benefits on Earth?

Answer. The physical science program contains research that spans the spectrum from applied to basic. Given the rigorous peer review to which the projects have been subjected, it is highly likely that these projects will have an impact on the scientific fields of which they are part. and hence provide great benefit to the Nation's scientific and engineering enterprise.

It is difficult to predict the impact of basic research. For example, NASA invested considerable resources aimed at understanding how variations in the surface tension of a liquid-vapor interface can lead to flow of the liquid. These projects lead to numerous advances in our fundamental understanding of surface tension driven flows. The technological impact of this basic research has recently become clear in the development of microchips, such as those used in DNA analysis. A leading approach to move the fluid through the channels on these chips is to use gradients in the liquid-vapor surface tension. The understanding of surface tension driven flows fostered by NASA funding has been used in the design of these chips. This example shows that basic microgravity research can have many unexpected benefits to problems of great concern here on Earth. Thus in assessing the potential impact of the physical sciences program one cannot neglect areas such as the fundamental physics effort with its focus on atomic clocks and low temperature physics.

Many of the programs in the physical sciences directly impact issues of concern here on Earth. The need to generate and use energy efficiently will be important in sustaining the economic growth that we have seen in the past. Many of the areas funded by NASA impact this effort. For example, microgravity experiments can be used to quantify the chemical kinetics of combustion. This information is critical in predicting the behavior of combustion engines used in automobiles and aircraft. New materials are needed to reduce the weight of vehicles and to increase the operating temperature of turbines that are used for propulsion and energy generation. NASA's work on phase formation, solidification, and computational materials science will all contribute to this effort. Multiphase flow and boiling are important in transferring heat from one region to another. NASA's work on multiphase flow will provide new understanding of these complex phenomena. Other areas where physical sciences research can impact life on Earth is the study of the granular flows that are central to many chemical processes on Earth. the wetting and spreading of fluids on surfaces that are so prevalent in many industrial processes, and understanding the process by which soot is produced by jet and diesel engines.

Question 2. Your prepared statement makes reference to research in flame propagation and fire detection and suppression. You describe the value of this research for long-duration space flight. What about the value of this research right here on Earth? Can it help in controlling or preventing such things as forest fires and fires in remote locations?

Answer.The heat generated by combustion on the Earth leads to strong convection. In a microgravity environment this convection is largely absent. Since this important perturbing effect is not present in microgravity, it is possible to study combustion phenomena in fundamentally new ways. The understanding that will be developed in such studies will unquestionably be central to our ability to detect and control fires on Earth.

Question 3. In what ways do you believe research in the physical sciences can enhance U.S. innovation and competitiveness?

Answer. As has been noted in the "American Competitiveness Initiative" by the Domestic Policy Council of the Office of Science and Technology Policy, innovation and competitiveness are fostered by a robust research program in the physical and engineering sciences, support for large scale facilities in which unique measurements can be made, and training the next generation of scientists and engineers. The physical sciences program at NASA contributes to all these goals. NASA research in the physical sciences impacts both current and future technologies. As mentioned above a future technology, microchips for bio and chemical assays, has been impacted by NASA's basic research on surface-tension driven flows. Research sponsored by NASA's physical sciences program has also impacted current technologies by drastically reducing the cost of producing liquid-phase sintered cutting tools, a $1.8 billion industry. The International Space Station (ISS) has the potential to be a large-scale research facility, similar to the Nation's accelerators and synchrotrons. Assuming that the necessary facilities, crew time and transport to and from the ISS are available, the ISS could function as a facility that eliminates the influence of gravity on a wide range of physical processes. As has been outlined in many National Research Council studies, this will allow a host of unique experiments to be performed from ultra sensitive atomic clocks to pattern formation during crystal growth. The vast majority of the grants supported by the Physical Sciences Division at NASA were given to universities. Thus, prior to the budget cuts in the Physical Sciences program, it supported approximately 1,700 graduate and undergraduate students. This support not only trained the next generation of scientists and engineers that are needed for the Nation to remain competitive, but through exposing undergraduates to research encouraged them to pursue careers in science and engineering.

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