THE FUTURE OF HUMAN SPACE FLIGHT

HEARING

BEFORE THE

COMMITTEE ON SCIENCE
HOUSE OF REPRESENTATIVES

ONE HUNDRED EIGHTH CONGRESS

FIRST SESSION

OCTOBER 16, 2003

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October 16, 2003

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THE FUTURE OF HUMAN SPACE FLIGHT

THURSDAY, OCTOBER 16, 2003

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE,
Washington, DC.

The Committee met, pursuant to call, at 10:18 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Sherwood L. Boehlert [Chairman of the Committee] presiding.

COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES
WASHINGTON, DC 20515

Hearing on

The Future of Human Space Flight

Thursday, October 16th, 2003
10:00 a.m.
2318 Rayburn House Office Building

WITNESS LIST

Dr. Michael D. Griffin
President and Chief Operating Officer
In-Q-Tel, Inc

Dr. Wesley T. Huntress, Jr.
Director
Geophysical Laboratory, Carnegie Institution of Washington

Dr. Matthew B. Koss
Assistant Professor of Physics
College of the Holy Cross

Dr. Alex Roland
Professor of History
Duke University

Dr. Bruce Murray
Professor of Planetary Science and Geology Emeritus
California Institute of Technology

HEARING CHARTER

COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

The Future of Human Space Flight

THURSDAY, OCTOBER 16, 2003
10:00 A.M.–12:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

1. Purpose

The Committee on Science will hold a hearing on *The Future of Human Space Flight* on October 16, 2003 at 10:00 a.m. in Room 2318 of the Rayburn House Office Building. The hearing will examine the rationale for human presence in space, the feasibility and cost of various potential long-term goals, and the near-term implications of establishing these goals.

2. Overarching Questions

The witnesses will outline their perspectives on human space flight and lay out various options that could be pursued. Overarching questions that will be addressed are:

- What is the U.S. likely to gain by the proposed options for human space flight and why could such gains not be obtained in other ways?
- What is a rough estimate of the costs of pursuing any of the proposed options? What is the approximate amount of time that it would take to achieve the goals of the proposed options?
- What are the technical hurdles that must be overcome in pursuing the options and the steps that must be taken to overcome those hurdles? (i.e., are there intermediate program goals and when might these be achieved?)
- What are the implications of the options for the current human space flight program? To what degree does the current program contribute to, or impede other options that could be pursued?

3. Key Issues

In the aftermath of the *Columbia* tragedy and the *Columbia* Accident Investigation Board report, the Nation has a rare opportunity to re-examine the vision and goals of the human space flight program. The following are some of the key issues:

Is there a compelling reason for human presence in space? The *Apollo* program to send a man to the Moon was clearly tied to a broader national goal, winning the Cold War. Today, NASA's human space flight program lacks a similar goal and is not tied to any national imperative. While NASA officials often argue that a human presence in space is necessary to carry out scientific research, even many advocates of human space flight suggest that science alone is not a compelling justification because much research can be conducted with unmanned probes. Instead advocates point to other rationales, including the human imperative to explore, a need for a strategic presence ,in space, the potential for technological spinoffs, and the possible development of human colonies in space, which they say could be especially important in the event of a natural or human-induced calamity on Earth.

What are the appropriate roles for robotic exploration and human exploration? Robotic spacecraft have landed on the Moon and Mars, and (in the case of the Soviet Union) on Venus. Robotic spacecraft have flown by every planet in the Solar System with the exception of Pluto, and NASA is currently developing a mission to that planet. Robotic spacecraft provide a wealth of scientific information and typically cost a fraction of what a human mission costs. In January 2004, NASA's Mars Exploration Rovers Mission will land two identical rovers, named Spirit and Opportunity, on the Martian surface to search for clues of water. This mission cost less than $1 billion. In some cases, robotic spacecraft and human missions work together to perform complementary tasks, such as when astronauts service and repair the Hubble Space Telescope or when robotic missions are used to scout out landing sites for human missions as was done before *Apollo*. Key issues include: What is the appropriate balance between robotic and human missions? What activities can only be accomplished with humans? Should NASA focus its efforts on robotic exploration until a suitable purpose can be developed and agreed upon for human exploration?

How would the Space Shuttle, the International Space Station and other aspects of the current human space flight program fit with any vision for NASA's future? Neither the Space Shuttle nor the Space Station has met its primary original goal. The Shuttle, for example, has not led to low-cost, routine, and reliable access to space; the Space Station is no longer being designed to provide a space-based platform to assemble and launch missions beyond Earth's orbit. Some advocates of a bolder mission for NASA argue that both the Shuttle and the Space Station consume large amounts of money simply to send humans repeatedly into Low-Earth Orbit (LEO) without moving toward any more ambitious or compelling goal. Others point out that the Space Station could contribute to future missions by providing data on how the human body reacts to prolonged stays in space. It is not clear how the Orbital Space Plane—the next vehicle on the drawing boards at NASA—would contribute to future missions. While NASA has talked about having the Space Plane contribute to longer-range goals, it is being designed only to ferry astronauts back and forth to the Space Station.

What technological barriers must be overcome? Human space flight is inherently dangerous. Human space exploration beyond Earth orbit is particularly hazardous because the radiation environment beyond the protective Van Allen belts[1] is much greater than the radiation levels experienced on the Space Station. Furthermore, the increased distance from Earth makes it impractical, and in some cases impossible, to return quickly if a problem arises. Also, it has been clearly demonstrated that near-zero-gravity has a slowly debilitating effect on human physiology. For example, astronauts can lose between six and 24 percent of their bone mass over the course of a year in space.[2] Depending on the duration and destination of the mission, improved technologies for propulsion, power, and life support systems may need to be developed.

What can we afford? The U.S. spends more than $6 billion annually on human space flight, including the Space Shuttle, Space Station, and Space Station research. This amount accounts for more than 40 percent of NASA's budget. Both Space Station and Space Shuttle have cost significantly more than originally expected and, following the Columbia tragedy, Shuttle costs are likely to increase. A large and sustained investment is likely to be necessary for any ambitious human space flight mission to succeed. NASA spending accounted for as much as 3.5 percent of the entire federal budget during the *Apollo* program, but today represents less than one percent of federal spending. Is the U.S. prepared to make NASA a sustained funding priority?

4. Background—Previous Studies on Future Goals for Space[3]

Over the last 40 years, numerous studies, commissions, and task forces have attempted to address the future of the U.S. civil space program, and the human space flight program in particular. The following provides a summary of several key studies.

National Commission on Space—(The Paine Commission, 1986)

In 1984, Congress created a commission to look at the long-term future of the civil space program. Chaired by former NASA Administrator Thomas O. Paine, the 15-member panel spent a year developing a 50-year plan. This plan was detailed in their report *Pioneering the Space Frontier*. In summary, the Commission called for the United States to lead the way in opening the inner solar system for science, exploration, and development. The Commission envisioned the establishment of bases on the Moon and Mars and the creation of a routine transportation system among the Earth, Moon, and Mars. The Commission emphasized that it was not trying to predict the future, but rather show what the United States could do if it chose to do so. The Commission envisioned human exploration missions returning to the Moon by 2005 and going to Mars by 2015. The report detailed a program involving

[1] The Van Allen Belts are layers of charged high-energy particles located above Earth's atmosphere (4000 to 40,000 miles up). The Earth's magnetic field traps the particles and protects astronauts on the Space Station from cosmic radiation.

[2] http://spaceresearch.nasa.gov/general_info/issphysiology.html

[3] Based on Congressional Research Service Report 95–873, Space Activities of the United States, CIS [the Commonwealth of Independent States] and other Launching Countries/Organizations 1957–1994, Marcia S. Smith, Specialist in Science and Technology Policy

both robotic and human exploration, acting synergistically to achieve the goal of opening the solar system. The report did not provide a cost estimate for carrying out its recommendations, but identified three principal benefits: (1) advancement of science and technology; (2) economic benefit of low-cost launch systems; and (3) opening up new worlds on the space frontier.

Leadership and America's Future in Space—(The Ride Report, 1987)

Astronaut Sally Ride's report *Leadership and America's Future in Space* was prepared as an internal NASA report. The report stated that the U.S. had lost its leadership in space and was in danger of being surpassed by other countries. The report argued that to regain leadership the U.S. space program must have two attributes: (1) a sound program of scientific research and technology development; and (2) significant and visible accomplishments. The report detailed four programs areas for comparatively near-term (15–20 year) activities: Mission to Planet Earth (now called Earth Science), robotic exploration of the solar system, a Moon base, and sending humans to Mars. The report recommended that NASA pursue programs in each of these areas. The report envisioned humans returning to the Moon by 2000, preceded by robotic probes to select a site for the Moon base. The report proposed one-year expeditionary missions to Mars between 2005 and 2010. The report concluded that settling Mars should be an eventual goal. As a result of the Ride report, NASA established the Office of Exploration to investigate long-range proposals for human exploration to the Moon and Mars.

President Bush's Space Exploration Initiative (SEI)—1989–1993

On July 20, 1989, the 20th anniversary of the first *Apollo* landing on the Moon, President Bush made a major space policy address, endorsing the goal of returning humans to the Moon and then going on to Mars "in the 21st Century." The program was referred to as the Space Exploration Initiative (SEI). At the time the President made his statement in 1989, the Director of the Office of Management and Budget suggested that the program would cost $400 billion over 30 years. While Congress endorsed the philosophy of the program, Congress was reluctant to approve the program because of the expected cost. The SEI program was formally terminated in 1993 and the NASA Office of Exploration was dismantled.

The Advisory Committee on the Future of the U.S. Space Program—(The Augustine Report, 1990)

In 1990, concerns about problems with several NASA programs (Hubble Space Telescope's flawed mirror, hydrogen leaks grounding the Shuttle for five months, and several issues with the Space Station program) prompted the White House to strongly encourage NASA to establish an outside advisory panel to reviews its programs and management. The panel was chaired by then-Chairman and CEO of Martin Marietta Inc., Norman Augustine. The panel recommended that NASA's budget increase by 10 percent per year after inflation. The report recommended activities for NASA in five major areas. They were: (1) Space Science (e.g., Hubble Space Telescope), which the report said should be NASA's highest priority and be maintained at 20 percent of NASA's overall budget; (2) Mission to Planet Earth (now called Earth Science); (3) Mission from Planet Earth, which would include robotic spacecraft needed as precursors to human exploration. The long-term goal would be human exploration of Mars. No specific timetable for this mission was set. Instead, the panel urged NASA to adopt a philosophy of "go-as-you-pay;" (4) space technology, (i.e., design of subsystems and materials for spacecraft) for which the report said spending should double or triple; and (5) development of a "heavy lift" unmanned, expendable launch vehicle to complement the Space Shuttle. The panel stated that if the 10 percent budget increases were not available the programs should be prioritized as follows: (1) Space Science; (2) Mission to Planet Earth; (3) heavy lift launch vehicle; (4) technology development: and (5) Mission from Planet Earth.

National Academy of Sciences Study—The Human Exploration of Space, 1997

In 1997, the Academy undertook a study of the role of science in human space exploration. The study examined scientific activities that must be conducted before human exploration beyond Earth orbit could be practically undertaken and science that would be enabled or facilitated by human presence. The study concluded that clear goals must be set and that an integrated science program, with the appropriate balance of human and robotic missions, to collect relevant data to enable future missions beyond Earth orbit should be pursued.

Columbia Accident Investigation Board (CAIB)—(The Gehman Report, 2003)

In its August report, the CAIB concluded that there was a problematic mismatch between NASA's missions and its budget. This occurred because NASA and/or Congress failed to scale back NASA's missions when funding did not match requested levels or when initial cost estimates proved to be inaccurate. The CAIB also pointed out that "for the past three decades, NASA has suffered because of the "lack. . .of any national mandate providing NASA a compelling mission requiring human presence in space." The CAIB stated that investments in a "next generation launch vehicle" will be successful only if the investment "is sustained over the decade; if by the time a decision to develop a new vehicle is made there is a clearer idea of how the new space transportation system fits into the Nation's overall plans for space; and if the U.S. Government is willing at the time a development decision is made to commit the substantial resources required to implement it." For further CAIB comments, see Attachment A.

5. Witnesses

Dr. Michael Griffin is the President and Chief Operating Officer of In-Q-Tel. He has nearly 30 years of experience managing information and space technology organizations. Dr. Griffin has served as Executive Vice President and CEO of Magellan Systems Division of Orbital Sciences Corporation, and as EVP and General Manager of Orbital Space Systems Group. Prior to that he served as both the Chief Engineer and Associate Administrator for Exploration at NASA, and at the Pentagon as the Deputy for Technology of the Strategic Defense Initiative Organization.

Dr. Wesley T. Huntress is the Director of the Carnegie Institution's Geophysical Laboratory. From 1993 to 1998 he was NASA's Associate Administrator for Space Science. In this position he was responsible for NASA's programs in Astrophysics, Planetary Exploration and Space Physics. Previously, he was Director of the Solar System Exploration Division. Dr. Huntress earned his B.S. in Chemistry at Brown University in 1964, and his Ph.D. in Chemical Physics at Stanford University in 1968. He is the recipient of a number of honors including the NASA Exceptional Service Medal.

Dr. Matthew B. Koss is an Assistant Professor of Physics of the College of Holy Cross in Worcester, Massachusetts. He has been the Lead Scientist on several Space Shuttle microgravity flight experiments flown on STS–62, STS–75, and STS–87. He received an AB degree from Vassar College in 1983 and a Ph.D. in Experimental Condensed Physics from Tufts University in 1989.

Dr. Alex Roland is Professor of History and Chairman of the Department of History at Duke University, where he teaches military history and the history of technology. From 1973 to 1981 he was a historian with NASA. He has written and lectured widely on the United States manned space flight program. He is past President of the Society for the History of Technology and of the U.S. National Committee of the International Union for the History and Philosophy of Science.

Dr. Bruce Murray is Professor Emeritus of Planetary Science and Geology at the California Institute of Technology. He was Director of the NASA/Caltech Jet Propulsion Laboratory from 1976 to 1982, which included the Viking landings on Mars and the Voyager mission through Jupiter and Saturn encounters. In 1979, he, the late Carl Sagan, and Louis Friedman founded The Planetary Society. He has published over 130 scientific papers and authored or co-authored six books. He received his college education at M.I.T., culminating in the Ph.D. in 1955.

6. Witness Questions

All the witnesses except Dr. Koss were asked to layout an option that they believed NASA should pursue and answer the following questions in their testimony:

- What is the U.S. likely to gain by your proposed option for human space flight and why could such gains not be obtained in other ways?
- What is a rough estimate of the costs of pursuing your proposed option? What is the approximate amount of time that it would take to achieve the goals of your proposed option?
- What are the technical hurdles that must be overcome in pursuing your option and the steps that must be taken to overcome those hurdles? (i.e., are there intermediate program goals and when might these be achieved?)
- What are the implications of your option for the current human space flight program? To what degree does the current program contribute to, or impede other options that could be pursued?

Dr. Koss was asked to answer these questions:

- How necessary is it to have the participation of people in space for successful research in material sciences? What proportion, if any, of the experiments now conducted on the Space Shuttle or Space Station could be conducted autonomously with unmanned systems? If researchers no longer had access to the Space Shuttle or Space Station how would advancement in the material sciences be affected?
- What alternatives exist to carry to orbit micro-gravity experiments that could be conducted autonomously if the Space Shuttle or Space Station were not available for whatever reason? If none, how much would it cost NASA to provide researchers such an alternative?
- To what extent, if any, would a more ambitious mission for NASA, such as sending people back to the Moon or to Mars, be likely to provide material science researchers with unique opportunities for experimentation?

7. Attachments:

- Attachment A: Excerpt from the Columbia Accident Investigation Board Report.
- Attachment B: NASA's five-year budget runout.
- Attachment C: Editorial by Dr. Matthew B. Koss.

ATTACHMENT A

Excerpted from the Columbia *Accident Investigation Board Report Volume 1, Chapter 9, August 2003.*

"Lack of a National Vision for Space"

In 1969 President Richard Nixon rejected NASA's sweeping vision for a post-*Apollo* effort that involved full development of low-Earth orbit, permanent outposts on the Moon, and initial journeys to Mars. Since that rejection, these objectives have reappeared as central elements in many proposals setting forth a long-term vision for the U.S. Space program. In 1986 the National Commission on Space proposed "a pioneering mission for 21st century America: To lead the exploration and development of the space frontier, advancing science, technology, and enterprise, and building institutions and systems that make accessible vast new resources and support human settlements beyond Earth orbit, from the highlands of the Moon to the plains of Mars." [4] In 1989, on the 20th anniversary of the first lunar landing, President George H.W. Bush proposed a Space Exploration Initiative, calling for "a sustained program of manned exploration of the solar system." [5] Space advocates have been consistent in their call for sending humans beyond low-Earth orbit as the appropriate objective of U.S. space activities. Review committees as diverse as the 1990 Advisory Committee on the Future of the U.S. Space Program, chaired by Norman Augustine, and the 2001 International Space Station Management and Cost Evaluation Task Force have suggested that the primary justification for a space station is to conduct the research required to plan missions to Mars and/or other distant destinations. However, human travel to destinations beyond Earth orbit has not been adopted as a national objective. The report of the Augustine Committee commented, "It seems that most Americans do support a viable space program for the Nation—but no two individuals seem able to agree upon *what* that space program should be." [6] The Board observes that none of the competing long-term visions for space have found support from the Nation's leadership, or indeed among the general public. The U.S. civilian space effort has moved forward for more than 30 years without a guiding vision, and none seems imminent. In the past, this absence of a strategic vision in itself has reflected a policy decision, since there have been many opportunities for national leaders to agree on ambitious goals for space, and none have done so."

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[4] National Commission on Space Pioneering the Space Frontier: An Exciting Vision of Our Next Fifty Years in Space, Report of the National Commission on Space (Bantam Books, 1986), p. 2.

[5] President George H.W. Bush, "Remarks on the 20th Anniversary of the Apollo 11 Moon Landing," Washington, D.C., July 20, 1989.

[6] "Report of the Advisory Committee on the Future of the U.S. Space Program," December 1990, p. 2.

ATTACHMENT B

NASA FY 2004 Budget
(Budget Authority - $ millions)

	Business as Usual	FULL COST					
By Appropriation Account **By Enterprise** **By Theme**	**Pres. Req. FY03**	**Est. Pres. Req. FY03**	**FY04**	**FY05**	**FY06**	**FY07**	**FY08**
Science, Aero, & Exploration	**7,015**	**7,101**	**7,661**	**8,269**	**8,746**	**9,201**	**9,527**
Space Science	**3,414**	**3,468**	**4,007**	**4,601**	**4,952**	**5,279**	**5,573**
Solar System Exploration	978	1,046	1,359	1,648	1,843	1,952	2,054
Mars Exploration	496	551	570	607	550	662	685
Astronomical Search for Origins	698	799	877	968	1,020	1,022	1,061
Structure & Evolution of the Univ.	331	398	432	418	428	475	557
Sun-Earth Connections	544	674	770	959	1,111	1,169	1,216
Institutional	370	–	–	–	–	–	–
Earth Science	**1,628**	**1,610**	**1,552**	**1,525**	**1,598**	**1,700**	**1,725**
Earth System Science	1,249	1,529	1,477	1,440	1,511	1,606	1,629
Earth Science Applications	62	81	75	85	87	94	96
Institutional	318	–	–	–	–	–	–
Biological & Physical Research	**842**	**913**	**973**	**1,042**	**1,087**	**1,118**	**1,143**
Biological Sciences Research	245	304	359	399	453	456	481
Physical Sciences Research	247	351	353	392	380	409	401
Commercial Research & Support	170	254	261	251	254	253	262
Institutional + AM + SAGE	181	3	–	–	–	–	–
Aeronautics	**986**	**949**	**959**	**932**	**939**	**934**	**916**
Aeronautics Technology	541	949	959	932	939	934	916
Institutional	445	–	–	–	–	–	–
Education Programs	**144**	**160**	**170**	**169**	**169**	**170**	**170**
Education	144	160	170	169	169	170	170
Space Flight Capabilities	**7,960**	**7,875**	**7,782**	**7,746**	**7,881**	**8,066**	**8,247**
Space Flight	**6,131**	**6,107**	**6,110**	**6,027**	**6,053**	**6,198**	**6,401**
Space Station	1,492	1,851	1,707	1,587	1,586	1,606	1,603
Space Shuttle	3,208	3,786	3,968	4,020	4,065	4,186	4,368
Space Flight Support	239	471	432	419	402	407	429
Institutional	1,192	–	–	–	–	–	–
Crosscutting Technology	**1,829**	**1,768**	**1,673**	**1,720**	**1,828**	**1,868**	**1,846**
Space Launch Initiative	879	1,150	1,065	1,124	1,221	1,257	1,224
Mission & Sci. Measurement Tec	275	434	438	435	439	439	444
Innov. Tech Trans. Partnership	147	183	169	161	168	172	179
Institutional	528	–	–	–	–	–	–
Inspector General	**25**	**25**	**26**	**28**	**29**	**30**	**31**
TOTAL	**15,000**	**15,000**	**15,469**	**16,043**	**16,656**	**17,297**	**17,806**

ATTACHMENT C

The New York Times

June 29, 2003, Sunday, Late Edition—Final

How Science Brought Down the Shuttle

BY MATTHEW B. KOSS

Matthew B. Koss is an assistant professor of physics at the College of the Holy Cross.

As a scientist whose experiments were carried out on three missions of the Space Shuttle *Columbia,* I have been following with great interest the findings of the board looking into the Shuttle's demise. Though a piece of foam may be found ultimately responsible, as the *Columbia* Accident Investigation Board announced last week, on some level I feel personally culpable for the loss of the seven astronauts. In-orbit experiments like mine have been used to justify manned space projects like the Shuttle for decades.

The truth is that the vast majority of scientific experiments conducted in orbit—including my own—do not require astronauts. The main reason for in-orbit experimentation is to observe how a scientific process works without gravity-driven influences. But almost all of these tests, save those that must be done on humans, can be controlled from the ground via computer or by robots in space. In fact, some of the best work is done this way when the crew is asleep, not moving about and causing vibrations.

To be sure, a lot of important science has been conducted in orbit. For example, research on the large single crystals of silicon that are at the heart of computer chips arose from the many detailed studies of crystal growth on the Space Shuttle. But, in fact, experiments like these are often more efficient and yield more fruitful results when done without the involvement of astronauts.

The science performed on the Shuttle can be classified as either a payload or a mid-deck laboratory experiment. Payload experiments are self-contained packages mounted in the payload bay, the wide open space in the back of the Shuttle. They either run autonomously or are controlled remotely via computers on the ground. Laboratory experiments are performed in the mid-deck or Spacelab module, and are done by the astronauts with computer assistance from the ground.

My experiments, on the fundamentals of how liquids turn into solids, were originally planned for the mid-deck, where they would be controlled by an astronaut who was scheduled to do eight tests. But because of launching delays, the project was changed to a payload experiment that would perform tests autonomously. During the flight, initial data was transmitted to the ground and analyzed by me and my colleagues. Performing the experiment remotely, without crew involvement, allowed us to do 63 test runs.

(Remote-controlled experiments may seem to contradict images we have grown accustomed to—of happy, busy astronauts manipulating scientific equipment or talking about the science on board, or occasionally reporting on the objectives of experiments. But this public image of astronauts as laboratory scientists working on their own experiments is a bit misleading. Since the Mercury 7 pioneers, the astronaut corps has served one overriding political and public relations purpose—to sell the space program.

The idea of using the Space Shuttle as a scientific laboratory actually came about after the Shuttle's design was already in place. The Shuttle program was conceived in the waning days of the *Apollo* program as the best option to continue a manned space program at the lowest cost. However, without a place to shuttle to, and not nearly enough satellites that needed a Shuttle to launch or repair them, the Shuttle program succeeded in doing little beyond creating a human presence in space. The idea of the Shuttle as an in-orbit lab was used as a justification for investment in its future.

Similarly, the International Space Station has been aggressively marketed as a science lab. In fact, the Station is seriously flawed in that too much crew time needs to be committed to Station maintenance, and too many of the planned experiments depend on crew operations when they could more effectively be done without them. In many cases, the crew is needed only to deploy an autonomous experiment.

Because of cost overruns and budget problems, the Station's crew was cut back to three from the planned seven. Originally, 120 astronaut-hours per week were to have been devoted to science; this has been cut back to 20 hours per week. With the Shuttle program grounded once again, it has become even more difficult to exchange crews, replace experiments or repair and refurbish equipment.

Scientific experimentation in space can be safer and more cost effective using long-duration remote controlled orbital spacecraft. At the outset, the costs of developing this technology may appear greater than simply perfecting the Shuttle. But if you do not need to provide a safe and sustaining environment for astronauts—making sure takeoffs and landings aren't too fast, providing enough food and oxygen—the overall cost will be significantly reduced.

If NASA is not able to convince the public of the importance of science in orbit without astronaut involvement, then so be it. At least America's refusal to support science would be honest, would not needlessly endanger human lives or compromise the integrity of science and scientists.

We will always need astronauts to assume certain risks to develop the technology that allows for human exploration of space. The space shuttles and space stations may be necessary to fulfill that mission. However, we need to separate the goal of scientific experimentation from the desire for space exploration. I hope that the unfortunate death of the *Columbia* astronauts will forever sever the false link that has been created between the two.

Astronauts do not risk their lives to perform scientific experiments in space. They fly to fulfill a much more basic and human desire—to experience the vastness of space.

Chairman BOEHLERT. Now we get to the main event.

I want to welcome the panel here today.

On the *Columbia* accident, both witnesses and Members repeatedly made the point that NASA has suffered from the lack of a clear national vision for the future of human space flight. Over the long-term, NASA will be successful only if it is pursuing progress to include an agreement to pay for whatever vision is outlined.

In many respects, we have the easiest task. It is easy for us to follow this program on a daily basis, are totally immersed in it, to have a grand vision, and authorize tons of money to help us achieve that vision, but it does no good if we just do our job and the appropriations don't follow, the Administration doesn't follow with the appropriate budgetary requests. NASA needs to do its part by coming up with credible cost estimates and schedules for projects, something that has been sorely lacking in recent decades, excuse me, and something that has not been done yet for the next human space flight project, the orbital space plane.

Second, we need to keep in mind that human space flight is not the only NASA responsibility or, as far as I am concerned, the most important of its responsibilities, important though it is. I think the Augustine Commission got it right back in 1990 when it listed space science and Earth science as NASA's top priorities and added several more activities in order of importance before it got to human space flight.

Third is a related point. NASA will not have an unlimited budget. The Federal Government has too few resources and too many obligations to give NASA a blank check. Anything that assumes massive spending increases for NASA is doomed to fail. That is especially true in the near future when the focus should be on getting the agency's house in order to carry out its current task.

Fourth, we need to be honest about the purposes and challenges inherent in human space flight. Our witnesses today are pretty honest in their testimony on this point and we thank them for that. The primary reason for human space flight is the human interest, some would say destiny, to explore. Human exploration is not necessarily the best way to advance science or technology and it certainly is the most expensive and riskiest way to do things. I would add that nothing about China's launch, and we congratulate the Chinese for the success of that mission, augment these statements.

Fifth, we need to learn from the mistakes we have made over the past 30 years. The Space Shuttle and the Space Station are remarkable achievements, something we are all too prone to forget, but they are also extraordinarily expensive projects, mind-bogglingly expensive compared to the original estimates, and they haven't performed as advertised or done as much as hoped to advance human exploration or knowledge. We have to avoid going down the same paths in the future.

So we need to be thoughtful and deliberate and coldly analytical in putting together a vision for the future of human space flight. It has to be a long-term vision. We are not about to embark on any crash program. The technical challenges alone are enough to prevent that.

We have assembled today an extraordinary panel to help sort these issues out, and I look forward to hearing from them.

The Chair recognizes the distinguished Ranking Member, the gentleman from Texas, Mr. Hall.

[The prepared statement of Mr. Boehlert follows:]

PREPARED STATEMENT OF CHAIRMAN SHERWOOD BOEHLERT

I want to welcome everyone here this morning to this important hearing. At our previous hearings on the *Columbia* accident, both witnesses and Members repeatedly made the point that NASA has suffered from the lack of a clear national vision for the future of human space flight. Over the long-term, NASA will be successful only if it is pursuing a clear and broad national consensus with sustained and adequate funding.

As the *Columbia* Accident Investigation Board (CAIB) noted in its report, that hasn't been the case for three decades.

Now, we ought to admit that one reason such a consensus has been lacking is that it's hard to reach and even harder to pursue over time. We need to be candid and realistic about that in our discussions today. And our vision can't be based on some dreamy, a historical view that we can recreate the *Apollo* era.

I, personally, don't know yet what that vision for the future of human space flight should be. Today's hearing is just the beginning of our efforts to build a national consensus. But I do think there are some principles and ideas we need to keep in mind as we develop a consensus.

First, any consensus has to be arrived at jointly by the White House, the Congress and NASA, and the consensus has to include an agreement to pay for whatever vision is outlined. NASA needs to do its part by coming up with credible cost estimates and schedules for projects—something that has been sorely lacking in recent decades and something that has not been done yet for the next major human space flight project, the Orbital Space Plane.

Second, we need to keep in mind that human space flight is not the only NASA responsibility, or, as far as I'm concerned, the most important of its responsibilities. I think the Augustine Commission got it right back in 1990 when it listed space science and Earth science as NASA's top priorities, and added several more activities in order of importance before it got to human space flight.

Third is a related point, NASA will not have an unlimited budget. The Federal Government has too few resources and too many obligations to give NASA a blank check. Any vision that assumes massive spending increases for NASA is doomed to fail. That is especially true in the near future when the focus should be on getting the agency's house in order to carry out its current tasks.

Fourth, we need to be honest about the purposes and challenges inherent in human flight. Our witnesses today are pretty honest in their testimony on this point. The primary reason for human flight is the human impulse—some would say destiny—to explore. Human exploration is not necessarily the best way to advance science or technology, and it certainly is the most expensive and riskiest way to do so. I would add that nothing about China's launch alters these statements.

Fifth, we need to learn from the mistakes we've made over the past 30 years. The Space Shuttle and the Space Station are remarkable achievements—something we are too prone to forget. But they are also extraordinarily expensive projects—mind-bogglingly expensive compared to the original estimates—and they haven't performed as advertised or done as much as hoped to advance human exploration or knowledge. We have to avoid going down the same paths in the future.

So, we need to be thoughtful and deliberate and coldly analytical in putting together a vision for the future of human space flight. It has to be a long-term vision; we're not about to embark on any crash program—the technical challenges alone are enough to prevent that.

We have assembled today an extraordinary panel to help us sort these issues out and I look forward to hearing from them. Mr. Hall?

Mr. HALL. Mr. Chairman, thank you for that brief statement, and I am going to put my statement in the record. It is one of the best ones I have ever read, and I am really recommending to the rest of the Committee and all who have access, but in the interest of time and because of the excellent panel that we have—and I was going to even quote Dr. Griffin, I will go and put his quote in there when he said, "The international faith and credibility of the United States is tied, in part, to the orderly completion of International Space Station. We must complete its construction to include the original seven-man crew capability and establish a utilization plan for the facility that returns as much value as possible."

And the last thing is I believe we have the means to start an exciting chapter in human exploration. We just need to decide where we want to go and then get started.

I would yield some time to the Chairman of the Space Subcommittee and yield back my time when he finishes with his time that I am lending him of my time.

[The prepared statement of Mr. Hall follows:]

PREPARED STATEMENT OF REPRESENTATIVE RALPH M. HALL

Good morning. I would like to welcome the witnesses to today's hearing. We appreciate all of you taking the time to come to the Hill to help us determine where the Nation should go with its human space flight program.

Today's hearing is especially timely given the successful launch and recovery of China's first astronaut. China is now the third nation to be able to send its people into space. I want to congratulate the Chinese people on this achievement, and I wish them well.

I would also note that the Chinese have indicated that this week's launch is just the first step in an ambitious and incremental program of human space exploration. It seems to me that we can take a lesson from their evident commitment to a phased set of goals for human space flight. I believe that we would profit as a nation from following that same approach.

Mr. Chairman, it is proper that we take some time in the aftermath of the Space Shuttle *Columbia* accident to determine the best path forward. However, I think we should move beyond a debate on whether or not we should have a human space flight program. There should no longer be a question of robotic versus human exploration—clearly, both will be needed to explore our solar system. Moreover, it has been clear since the early years of the Space Age that the human exploration of space is a fundamental expectation of the American people—indeed of people all over the world. Revisiting the debate over the role of human space flight in the aftermath of an accident is understandable. However, I think that it also symptomatic of our unwillingness as a nation to commit to a clear set of goals for. the human space flight program and to the resources required over the long haul to achieve them. We can and should do better.

As you know, Rep. Nick Lampson on our Committee has re-introduced legislation that he first introduced in the 107th Congress. His bill, the "Space Exploration Act of 2003" (H.R. 3057), would establish a phased set of goals for America's human space flight program, whereby the achievement of each goal helps provide the capabilities needed to attain successive goals. Adoption of Rep. Lampson's bill would go a long way towards providing a rational framework for our human space exploration investment decisions. I am happy to be a co-sponsor, and I hope that other Members will join me in the coming days.

However, whatever legislative approach we wind up taking, I hope that today's hearing will start the process of coming to some consensus on concrete goals.

At the same time, we cannot allow our focus on the future to distract us from the needs of the present. It is clear to me that any talk of bold new human exploration initiatives will ring hollow unless we are first prepared to meet our existing commitments. In particular, I would echo the sentiments expressed by one of our witnesses, Dr. Griffin, when he states: *". . .the international faith and credibility of the United States is tied, in part, to the orderly completion of the International Space Station. We must complete its construction, to include the original seven-man crew capability, and establish a utilization plan for the facility that returns as much value as possible."*

In addition, NASA will need to ensure over the near-term that adequate contingency plans are in place to protect the viability of the Space Station in the event of further delays in the Shuttle return-to-flight schedule. I hope and expect that such plans are in preparation.

Mr. Chairman, budgets are likely to be tight for the foreseeable future. That's the reality. As a result, it is even more important that Congress and the Administration need to work together to come up with a clear set of goals for the future of the human space flight program. Given goals, we can then determine how much we can afford to expend on an annual basis towards meeting those goals. I believe we have the means to start an exciting chapter in human exploration. We just need to decide where we want to go and then get started.

Chairman BOEHLERT. Are you yielding to Mr. Rohrabacher or Mr. Gordon?

Mr. HALL. Well, either one.

Chairman BOEHLERT. It is—the Chair recognizes the distinguished Ranking Member of the Subcommittee on Space.

Mr. HALL. And I ask that my entire statement be placed in the record.

Chairman BOEHLERT. We would not miss that.

Mr. HALL. Thank you, sir.

Chairman BOEHLERT. Without objection, so ordered.

Mr. GORDON. Thank you, Mr. Chairman, and thank you, Mr. Hall, for yielding your time.

Let me first state that I listened to the Chairman's remarks with interest. And I want to say that I thought they were thoughtful. I concur. I think that it is a good benchmark for all of us, and——

Mr. HALL. Don't thank him too much. He is hard to live with.

Mr. GORDON. Well, I mean this believer is right. And I think that if we follow that lead we will go on in a very good direction.

We do need to get on and hear the witnesses, so let me just add my quick welcome. There are a couple of issues that I would like to hear discussed today. First, while I am obviously not an expert in these matters, it seems to me that having a base on the Moon would be a useful step for a variety of reasons, one of which certainly would be further human space exploration, if nothing else. Such a base would be needed to test many of the technologies and techniques required for human exploration. I would like to know your theories on that.

Also the NASA Administrator says his vision for exploration is not about destinations. Instead, NASA will first develop technologies and then decide where to go. Somehow, that seems backwards to me. It seems to me that unless we are willing fully to commit to some concrete goals, NASA's technology investments will lack and be unfocused, inefficient, and wind up costing more than necessary. In addition, the reality is the technology programs that are not tied to specific and agreed-upon mission goals become very vulnerable to budget cuts or even cancellation over time.

So as you go through your remarks, I hope that you can address these two issues. And thank you very much for being here with us today.

Chairman BOEHLERT. Thank you very much. And all other Members of the Committee are at leave to enter your remarks in the record at this juncture.

[The prepared statement of Mr. Rohrabacher follows:]

PREPARED STATEMENT OF REPRESENTATIVE DANA ROHRABACHER

I want to thank the Chairman for holding this timely hearing on the *Future of Human Space Flight*. *Columbia*'s tragic destruction has once again demonstrated that the risk of human space flight include the ultimate sacrifice, and *Columbia*'s courageous crew understood that. Their sacrifice, however, may provide this nation the needed spark to re-examine its requirements for exploring and conquering space. Because we are spending a lot of money and lives for exploration and discovery, the Nation must know why it is sending humans into space.

The American space experience is about expanding human freedoms and having higher expectations. We do neither if we lack a clear vision of purpose for our national civil space program. Unlike the 1960s, today's NASA lacks a unifying and overarching purpose for planning human space flight missions beyond the Space

Station. While we struggle with finding a compelling reason for a human presence in space, the Chinese Government had sent its first astronaut into orbit last Tuesday evening. If this flight is successful, the Chinese hope to possibly build a space station and explore the Moon within this decade. Recent scientific studies reveal that the Moon may contain five times more water than previously believed, as well as minerals that hold the promise of clear burning fuel for use here on Earth. The Chinese long-term human space flight program suggests that the Moon is more than just a place for planting flags and picking up rocks.

China's quest for reaching the stars, however, is driven by more than discovery. The U.S. national security community has always suspected that China's ballistic missile and military reconnaissance capabilities are major components of a "national integrated space capability" with human space flight being a key element. I fear human space travel that beckons China will be used to tout its communist system. We must seize the opportunity now to develop a new game plan for our human space flight program—not to mimic a foreign power's pursuits, but to honor those courageous individuals that sacrificed all, and to benefit humankind.

The tragic episodes of *Columbia, Challenger,* and even the first *Apollo* mission must not weaken our resolve to meet the challenges in the decades to come.

Thank you, Mr. Chairman.

[The prepared statement of Mr. Smith follows:]

PREPARED STATEMENT OF REPRESENTATIVE NICK SMITH

This is an important hearing discussing future of human space flight. I would also like to thank our distinguished witnesses for joining us.

The real question we need to be asking is "What is the purpose of NASA?" Our last hearing revealed that there is little consensus on this fundamental question. Only once this question is answered, can we ask how human space flight contributes to that purpose.

So what should be the purpose of NASA? One perspective is that NASA could continue as a scientific research program. NASA has had successes with a scientific research oriented policy. We have sent probes to Mars, Venus, Jupiter, and the outlying planets. Data, collected by the Galileo probe, which ended its mission last month, suggests that there is much room for important research to be continued in Jupiter's moons. The Hubble telescope is producing important insights into the nature of the universe. For example, just in the last six months, scientists have used the Hubble to confirm Einstein's hypothesis about dark energy. Automated and remotely controlled experiments on the Shuttle have been extremely fruitful. NASA has had and should have a science-first orientation, and it has had dramatic successes and can make substantial scientific advances.

Others propose that advancing human space flight should be front and center of NASA's purpose. Advocates of this position argue that we should, in effect, continue and extend President Kennedy's vision to occupying the Moon, Mars, and low-Earth orbit. Kennedy wanted to demonstrate the superiority of American technological and economic power.

I do not find this persuasive. We were not pursuing human space flight for the sake of human space flight. We were furthering a national agenda by proving the superiority of our economic and political system. Today, this purpose is not there, and this argument does not translate well to today, even with yesterday's completion of the Chinese mission.

Some people have argued that we need to continue human space flight to support scientific research. However, both Dr. Roland and Dr. Koss indicate in their testimony today how little scientific benefit human presence provides. Only human physiological research requires humans in space.

The question must be: what produces the best and most cost effective scientific research? The problem with manned space flight is that whatever mission the flight started with, the mission always becomes getting the people back home safely. This not only undermines the scientific mission, but it increases costs enormously.

Again, I would like to thank the Chairman and Ranking Member for holding this hearing on the future of human space flight. It serves to shine a light on the important issue that this committee must grapple with: what is the purpose of NASA?

[The prepared statement of Mr. Costello follows:]

PREPARED STATEMENT OF REPRESENTATIVE JERRY F. COSTELLO

Good morning. I want to thank the witnesses for appearing before our committee to examine the range of options for the future of the Nation's human space flight program.

When NASA began 45 years ago, there was a national drive and enthusiasm for space exploration. The *Apollo* program to send an American to the Moon by the end of the 1960s was tied to the broader national goal of winning the Cold War. With both the President and the country energized, the U.S. was able to reach new heights and accomplish its goal by landing on the Moon in 1969. In an era when Shuttle launches are commonplace, this enthusiasm has significantly decreased. In the aftermath of the *Columbia* accident and the *Columbia* Accident Investigation Board report, we have an important opportunity to examine the goals of the human space flight program and make comprehensive decisions about its future direction.

My colleague, Nick Lampson, has taken an important first step in by introducing H.R. 3057, the *Space Exploration Act,* and I am pleased to be a co-sponsor. His legislation assists in establishing a vision for NASA's human space flight program. H.R. 3057 sets specific incremental goals that are challenging and build capabilities and infrastructure needed for an ultimate human mission to Mars. The goals established by the *Space Exploration Act of 2003* are sequenced in terms of increasing difficulty and complexity. Achieving the earlier goals will provide the capabilities needed for humans to explore other parts of the inner solar system while supporting the Nation's scientific objectives. It is my hope the Committee will incorporate these goals in a NASA reauthorization bill.

Further, as you know, China recently launched its first astronaut into orbit and intends to continue a long-range program of human space flight activities. I am interested to know how a sustained Chinese human space flight program will impact the United States.

I welcome our panel of witnesses and look forward to their testimony.

[The prepared statement of Ms. Johnson follows:]

PREPARED STATEMENT OF REPRESENTATIVE EDDIE BERNICE JOHNSON

First of all, I would like to thank Chairman Boehlert and Ranking Member Hall for calling us together to discuss this all too important issue.

The purpose of this hearing is to examine obstacles to advancing commercial human space travel.

In 1961, President Kennedy set the national policy goal of landing an American on the Moon by the end of the decade of the 1960s.

I have said this many times before, and I will say it again: The space exploration research program has been one of the most successful research programs in the history of this country. Research provided by our human space program has yielded many lifesaving medical tests, accessibility advances for the physically challenged, and products that make our lives more safe and enjoyable.

Over 40 years ago, our leaders in the space program had the foresight to get us to get into this type of research. We also owe those leaders some homage for their foresight, and I am hoping that we will then have the foresight to continue this type of research.

Currently, there is substantial debate on how our Human Space Flight program should continue. Some contend that human space flight is currently too risky and we should reduce flights or rely upon robotic surrogates. Others contend that the value we gain from human space flight warrants the risk and that we should return to flight levels we had before the *Challenger* disaster.

But it is imperative that we stay ever so mindful of the safety issue. Space travel is inherently dangerous. Our success in this vital national endeavor depends on our never overlooking this basic truth. The assets and human lives that are risked in the exploration of space serve to underscore the value we place on the broad global benefits that it brings. The investment we make in their safety should equally underscore the value we place on them.

[The prepared statement of Mr. Lampson follows:]

PREPARED STATEMENT OF REPRESENTATIVE NICK LAMPSON

I would like to welcome China into the human space flight club. As only the third nation to successfully launch a manned spacecraft, China truly has achieved an amazing feat with the launch of Shenzhou 5. I was pleased to see Yang Liwei return safely yesterday and look forward to future peaceful Chinese space missions.

It has been reported that China has plans for future missions, including the development of a space station and human exploration of the Moon. While I do not believe that China's future human space flight plans should be interpreted as the beginnings of a 1960's era "space race," yesterdays successful mission means that we can't continue business as usual at NASA.

History has shown that great nations explore. The United States must not turn its back on human space exploration at this critical time. We must return the Space Shuttle to flight and complete construction of the International Space Station. At the same time, this Administration and this Congress must provide the American people with a vision and a concrete set of goals for the Nation's future human space flight program. It is clear that China has goals set by its leadership, and we need the same.

I am attempting to push NASA in this direction with my *Space Exploration Act* (H.R. 3057). This bill requires NASA to design and implement a long range vision for our future in space.

The phased series of goals over the next 20 years that I propose in this legislation includes human visits to the Earth-Sun liberation points and Earth-orbit crossing asteroids, deployment of a human-tended research and habitation facility on the Moon, and human expeditions to the surface and moons of Mars.

Once America gets started on achieving the first of the human space flight goals listed in the bill, we have gotten over the highest hurdle to success in the entire initiative. We will once again be moving outward beyond low-Earth orbit. And in the process, we will revitalize our space program, energize our industrial and academic sectors, create new opportunities for international cooperation, and inspire our young people.

The real obstacle we face in overcoming the drift in the Nation's human space flight program is not technological and it's not financial—it's the lack of commitment to get started.

Yesterday China showed that they are committed to future space exploration—will the United States follow suit?

[The prepared statement of Ms. Jackson Lee follows:]

PREPARED STATEMENT OF REPRESENTATIVE SHEILA JACKSON LEE

Mr. Chairman,

Thank you for calling this important hearing to explore the future of the human space flight mission of NASA. I would also like to commend Ranking Member Hall, as well as the Chair and Ranking Member Gordon of the Space Subcommittee for their leadership, and tireless work since the tragedy of February 1st to ensure that Congress and NASA are on the same page—working together to find the best way to get NASA's vital mission back on track.

I am committed to the mission of NASA. NASA plays many roles, and means so much to America today. NASA is a source of dreams for our young and old alike. It provides insights into the origins and destiny, and wonder, of our universe. On the way to this noble goal, NASA develops innovations that spur on our economy and keep us on the cutting edge of technology.

NASA also inspires young engineers and scientists to push their minds to new levels of excellence. These people become role models for future generations of intellectual pioneers. I believe that there is something about the majesty of seeing humans in space that has a unique capability to drive young imaginations and aspirations.

I also believe that it will be the young scientists and explorers in space, looking at the universe unfolding around them, who come up with the next great discoveries and visions of future missions. Probes and robotics can do a lot, but they cannot look around and wonder, or dream, or be creative. That is the role of humans, and therefore, must be a role of the NASA human space flight mission.

I do not want to see NASA become an exhibit in museums and history books, instead of being the leader in technology and exploration that it should be. At NASA over the past decade, there seems to be a fundamental disconnect between logic and policy. I feel one the underlying causes of this disconnect is the lack of a clear vision for the future of NASA. Once that vision is created, once a mission is designed, I believe that the needs to fulfill that mission will become much more obvious. As we decide the needs, I am confident that American policy makers, American scientists and engineers, and the American people will step up the plate and launch us into the next millennium. The first step though, must be the vision.

Key reports—from the Paine Commission, the Ride Report, President Bush's SEI in 1993, and the Augustine Report—all talked of exciting and provocative missions, usually to Mars, or back to the Moon to set up a human colony. But decades later, we still are not making notable progress toward either of those goals.

It seems that we are close to glory in space, but are just not demonstrating the necessary commitment, and boldness. That is why I joined my colleague from Houston, Nick Lampson, in sponsoring H.R. 3057, which would "restore a vision for the United States human space flight program by instituting a series of incremental goals that will facilitate the scientific exploration of the solar system and aid in the search for life elsewhere in the universe, and for other purposes." It would send a clear signal to the American people and to the world that America will be a leader in space, and that great things are to come.

I thank this distinguished panel for taking the time to join us here today. I look forward to hearing their ideas about the role of humans in space exploration, and how they can fulfill that role safely. I think that H.R. 3057 is a strong start, but it will need to be refined to fit existing technology and scientific necessities. We all need to work together in this endeavor.

NASA is obviously at a crossroads, and now is the time to make decisions and move forward.

Chairman BOEHLERT. And we will go right to our very distinguished panel of witnesses: Dr. Michael D. Griffin, President and Chief Operating Officer of In-Q-Tel, Inc.; Dr. Wesley T. Huntress, Jr., Director of Geophysical Laboratory, Carnegie Institution of Washington; Dr. Matthew B. Koss, Assistant Professor of Physics, College of the Holy Cross; Dr. Alex Roland, Professor of History, Duke University; and Dr. Bruce Murray, Professor of Planetary Science and Geology Emeritus, California Institute of Technology.

Let me say at the outset how much we appreciate all of you for being resources for this committee. We are here to listen. We are here to learn. We are here to have a dialogue as we develop a future vision for this important program.

With that, Dr. Griffin, you are up first. And I would ask that you try to confine your opening remarks, and the Chair will not be arbitrary, to five minutes or so, which will give us ample opportunity to have the dialogue I referred to. Dr. Griffin.

STATEMENT OF DR. MICHAEL D. GRIFFIN, PRESIDENT AND CHIEF OPERATING OFFICER, IN-Q-TEL, INC.

Dr. GRIFFIN. Thank you, Mr. Chairman and Members of the Committee for inviting me to appear and giving me this opportunity to discuss the vision, the goals, and the future of human space flight.

I will begin at this time to discuss what we should do and not what we have done wrong. I believe that the human space flight program is, in the long run, probably the most significant activity in which our nation is engaged. For what, today, do we recall renaissance Spain, King Ferdinand, and Queen Isabella? Unless one is a professional historian, the memory which is evoked is of their sponsorship of Columbus in his voyages of discovery. For what, in 500 years, will our era be recalled? We will never know, but I believe it will be for the *Apollo* lunar landings, if for anything at all. And this is entirely appropriate. Human expansion into space is a continuation of the ancient human imperative to explore, to exploit, to settle new territory when and as it becomes possible to do so. This imperative will surely be satisfied, by others if not by us.

It may be argued that we have many difficult problems in greater need of immediate attention and resources than is human space flight. I agree with this argument. But even recognizing this reality, space flight is sparingly funded. In round numbers, fiscal year 2003 U.S. budget outlays were approximately $2.1 trillion while the U.S. population is currently just under 300 million, yielding an average liability of $7,000 per person, or about $20 a day for every man, woman, and child in the Nation. With the NASA budget at $15 billion a year, the civil space program costs each person in the Nation about $50 a year, or less than 14 cents per day. A really robust space effort could be had for a mere 20 cents a day from each person. I spend more than that on chewing gum. We, as a nation, quite literally spend more on pizza than we do on space exploration. So I don't think we are overspending on space. As wealthy as the United States is, it is certainly true that we can allocate only a small fraction of that wealth to the development of human space flight. But, in my opinion, we must allocate that fraction and we must spend it wisely. I don't think we are doing either.

I think that although there are technical challenges, they do not seem to me to be the biggest problem that we have. We did not retreat from the Moon because of technical difficulties, we have not failed to go to Mars because of technical problems, and we have not taken 20 years to put a Space Station in orbit because of technical matters. In each case, the issues are matters of politics and leadership. Without a bipartisan, leadership-driven consensus that a vigorous space exploration program is essential to America's future, we will not have such a program, whether or not there are technical challenges to be overcome. It has been 40 years since a Chief Executive has propounded such a vision and made it stick, and no Congress has ever taken the initiative to do so. If the Nation's leaders can not say that space exploration is important and why, it will not occur.

"This new ocean," to use John F. Kennedy's famous phrase, has recently become accessible to us, albeit at great cost and difficulty. But despite the difficulty, it will be explored and exploited, it will be settled, by humans. The only questions are: which humans and when. While the answer to the first question will eventually be all humans, I am parochial enough to believe that those from our nation should be in the vanguard.

So, recognizing that others may differ, for me, the single overarching goal of the human space flight program is the human settlement of the solar system and eventually beyond. I can think of no lesser purpose sufficient to justify the difficulty of the enterprise, and no greater purpose is possible.

With that, I stand ready to take your questions. Thank you very much.

[The prepared statement of Dr. Griffin follows:]

PREPARED STATEMENT OF MICHAEL D. GRIFFIN

Abstract

Justification for the human space flight program is discussed in terms of the importance of U.S. leadership in this historically inevitable expansion. The need for a steady funding and a long-term commitment to the space flight enterprise is discussed. Technology hurdles and suggested intermediate milestones are identified.

Mr. Chairman:

Thank you for inviting me to appear before the Committee in this rare opportunity to discuss the vision, the goals, and the future of human space flight.

Allow me to begin, if I might, with some "truth in advertising." I am an unabashed supporter of space exploration in general, and of human space flight in particular. I believe that the human space flight program is in the long run possibly the most significant activity in which our nation is engaged. For what, today, do we recall renaissance Spain, King Ferdinand, and Queen Isabella? Unless one is a professional historian, the memory which is evoked is their sponsorship of Columbus in his voyages of discovery. For what, in five hundred years, will our era be recalled? We will never know, but I believe it will be for the *Apollo* lunar landings if for anything at all. And this is entirely appropriate. Human expansion into space is a continuation of the ancient human imperative to explore, to exploit, to settle new territory when and as it becomes possible to do so. This imperative will surely be satisfied, by others if not by us.

We know this, if not with our logic then with our intuition. We are all the descendants of people who left known and familiar places to strike out for the risky promise of better places, in an unbroken chain going back to a small corner of east Africa. Concerning the settlement of the American West, it has been said that "the cowards never started, and the weaklings died on the way." But this has been true of every human migration; we are all the descendants of those who chose to explore and to settle new lands, and who survived the experience.

The late Carl Sagan, and others, have argued that this biological imperative is soundly rooted in evolutionary biology. The divergence of a species throughout the broadest possible environmental range is a form of insurance against a local catastrophe. Sagan argued that human expansion into the solar system is the important next step in protecting the human species from known and unknown catastrophes on a planetary scale. The fossil record which has been unearthed in recent decades certainly gives credence to this view, revealing evidence of multiple large scale "extinction events" throughout the history of life on Earth.

However, to be important is not necessarily to be urgent, and it may be argued that we have many difficult problems in greater need of immediate attention and resources than is human space flight. But even recognizing this reality, space flight is sparingly funded. In round numbers, FY 2003 U.S. budget outlays were approximately $2.1 trillion, while the U.S. population is just under 300 million, yielding an average liability of $7000 per person, or about $20 per day for each man, woman, and child in the Nation. With the NASA budget at $15 B/year, the civil space program costs each person in the Nation about $50/year, or less than 14 cents per day. A really robust space effort could be had for a mere twenty cents per day from each person! I spend more than that on chewing gum. We as a nation quite literally spend more on pizza than we do on space exploration. So I don't think we are overspending on space. As wealthy as the United States may be, it is certainly true that we can allocate only a very small fraction of that wealth to the development of human space flight. But we *must* allocate that fraction, and we must spend it wisely. I don't think we are doing enough of either.

"This new ocean"—to use John F. Kennedy's famous phrase—has recently become accessible to us, albeit at great cost and difficulty. But despite the difficulty, it will be explored and exploited, it will be settled, by humans. The only questions are, "Which humans?" and "When?" While the answer to the first question will eventually be "all humans," I am parochial enough to believe that those from our nation should be in the vanguard.

Much in the news lately is the budding Chinese space program, which came of age yesterday with its first manned launch. The United States required only eight years to progress from our first manned space flight to the first lunar landing, and that while simultaneously developing the technology to do it. A committed nation could now achieve such a goal much more expeditiously. How are we going to feel when one of the *Apollo* lunar landing flags is returned to Earth and displayed in a museum—in Beijing? Do we really want a world in which the human space flight programs of other nations are on the rise, while ours is in decline? We are the sole factor in determining whether such a future comes about. No other nation can surpass us in human space flight unless we allow it to happen.

So, recognizing that others may differ, for me the single overarching goal of human space flight is the human settlement of the solar system, and eventually beyond. I can think of no lesser purpose sufficient to justify the difficulty of the enterprise, and no greater purpose is possible.

With these thoughts in mind, I offer the following in response to the questions posed by this committee in its formal invitation to appear.

- *What option should NASA pursue in human space flight?*

Accepting my premise that the proper goal of a publicly-funded space program is to enable the human settlement of the solar system, it becomes immediately clear that the relevant possibilities are few in number, and that we have not recently pursued any of them.

The geography of the solar system shows us the way. Suitable and useful destinations for humans are limited in the near-term, given technologies reasonably foreseeable in the next several generations. They include the Moon, Mars, and certain near-Earth and main-belt asteroids. That's about it. Certain way-points or "parking places"—not physical destinations but features of the orbital geography of the solar system—are also useful, including low-Earth orbit (LEO), geostationary orbit (GEO), and possibly the lunar Lagrange points. We, and our grandchildren's grandchildren, will be fully and gainfully occupied learning to reach, survive in, and exploit these places to our benefit.

It has been drolly observed that, "if God had wanted us to have a space program, he would have given us a moon," and I believe the truth underlying this witticism is correct. Development of permanent lunar bases on the Moon, only three days away, will teach us much of what we need to know to press on to Mars. And in the slightly longer run, I believe the asteroids will be found to have immense value as a source of raw materials, as well as being of great scientific interest.

So, to me, the proper sequence for exploration is the Moon, then Mars, and then the asteroids. It must be recognized, of course, that any such sequence is for initial program planning only. Once begun, exploration and exploitation of the Moon will continue for centuries or millennia, just as it will for Mars and beyond.

The waypoints—LEO, GEO, and others—should be developed as necessary to enable the exploration of the Moon, Mars, and asteroids, and not as programmatic goals in and of themselves. For example, a LEO space station such as the present International Space Station (ISS) is of very little use in developing a lunar base, especially during the early phases of such development. Thus, in a human space flight program focused on "settling the solar system," construction of a LEO space station would not be an early priority.

Similarly, there has been considerable discussion concerning the utility of the lunar Lagrange points as transportation nodes for a lunar base. While I think the idea has considerable merit, it is merit that attaches mostly to the longer term, when a fairly robust space infrastructure has been put in place. In the early years, the best way to get to the Moon is as directly as possible, and similarly for Mars.

- *What is the U.S. likely to gain by pursuing this option, and why can such gains not be obtained in other way? Specifically, please describe why these gains could not be achieved by means of unmanned missions. What are the implications of the option you suggest for the future of the unmanned program?*

One may search in vain for an argument justifying, in any immediate way, the danger, difficulty, and expense of human space exploration. I believe we have all heard enough about technological "spinoffs," stimulating education, maintaining the high-tech industrial base, conducting astronomical or geological research, developing space-based power systems, harvesting space resources, and so on *ad nauseam.* Such arguments are most annoying because, while they are true—the claimed benefit does exist—they are irrelevant. No thinking individual would undertake a multi-generation program of human space flight to achieve any of these objectives, or any other similar collateral benefit. Any such goal can and should be achieved more directly and efficaciously merely by allocating to it the resources judged to be necessary for its accomplishment. We do not need a human space flight program to stimulate our children's education, or for any similar reason. A more global rationale is needed for an enterprise that will occupy our attention for generations to come.

What the U.S. gains from a robust, focused program of human space exploration is the opportunity to carry the principles and values of western philosophy and culture along with the inevitable outward migration of humanity into the solar system. Is this valuable? The answer must depend on one's world view, I suppose. But consider a map of the world today, and notice the range of nations in which English is spoken as a primary language, and in which variations on British systems of justice, politics, culture, and economics thrive today. Was the centuries-long development of the British Empire, based upon Britain's primacy in the maritime arts, a misguided use of resources? I believe not.

Consider also that Great Britain's influence, achieved through its mastery of the oceans, was not restricted merely to affairs in the colonies, the new lands. By virtue of its nautical superiority, Britain wielded a dominant influence in the Old World as well, an influence hugely out of proportion to its size and other resources.

Can America, through its mastery of human space flight, have a similar influence on the cultures and societies of the future, those yet to evolve in the solar system as well as those here on Earth? I think so, and I think our descendants will consider it to have been worth twenty cents per day.

In the process of developing and extending human space flight into the solar system, we will also collect all of the ancillary benefits mentioned above, and many more. But I cannot imagine that these benefits can be attained solely through the use of unmanned scientific and exploration spacecraft. While such efforts are incredibly valuable—and I have personally spent the majority of my career in the engineering development of unmanned space systems—it is not credible to believe that they can substitute for human presence in the larger context that I have outlined here. Perhaps the most concise rationale on this point was provided by Norm Augustine in his 1990 "Report of the Advisory Committee on the Future of the U.S. Space Program." In that document, Mr. Augustine points out that "there *is* a difference between Hillary reaching the top of Everest and merely using a rocket to loft an instrument package to the summit." It cannot be said better, and again, I believe this difference is worth a few cents per day. Others may differ, but that is my view.

To this point, there is no inherent conflict between manned and unmanned space programs, save that deliberately promulgated by those seeking to play a difficult and ugly zero-sum game. But that is not the game at hand. In the context of a civil space program justified primarily in terms of the expansion of humanity into the solar system, it must be understood that "primarily" does not mean "entirely." Certain unmanned space systems having little connection with human space flight will be supported—as they are today—because of their inherent scientific or utilitarian value. Who today wants to return to life without weather satellites, global navigation, instantaneous worldwide communication, or high resolution overhead imaging? Similarly, that portion of our nation's scientific research devoted to using space assets to improve our understanding of Earth's environment, our solar system, and the cosmos beyond, will always, and should always, receive due attention in the allocation of resources. I personally worked, as a much younger engineer among thousands of others, on the Hubble Space Telescope, and will always be proud of having done so.

Human space flight advocates are not making a case that such programs should be deferred in favor of manned programs. On the contrary, the necessary requirements of human expansion into the solar system cannot be met without a greatly increased program of unmanned scientific exploration. This can only be seen as a "win-win" for all those involved in any aspect of space exploration. In the end, it comes down to letting robots and humans each do what they do best.

- *What is your estimate of the costs of pursuing the selected option?*

The cost cannot be easily estimated, because the task is so open-ended. A better way to think of the space enterprise is as an investment that will yield some benefits in the near-term, but which cannot fully mature for generations. The appropriate fiscal policy for such an investment is to allocate to it an amount consistent with both its ultimate value and the sobering reality that it will be a long time before this value is returned. Our present assessment, as a nation, seems to be that the space enterprise is worth about $15 B per year, or as I indicated earlier, about 14 cents per person per day. I think we could spend a little more without wasting the money.

The Nation's space program, and in particular its human space flight program, is not presently focused along the lines I have suggested here. We are burdened with a history of several decades of, in my view, misguided policy decisions, the legacy of which cannot be easily or quickly undone. For example, though I struggle to find value in the effort to match its cost, the international faith and credibility of the United States is tied, in part, to the orderly completion of the ISS. We must complete its construction, to include the original seven-man crew capability, and establish a utilization plan for the facility that returns as much value as possible. Yet, we must not mortgage our future to ISS, losing the next two decades as we have lost the last two. If no additional funding can be made available, it will be very difficult to complete ISS and, at the same time, embark on the development of those other systems that are required for a truly valuable and exciting human space flight program.

I would like to see an allocation of about $20 B per year to the U.S. civil space program. This would enable us to begin crucially needed programs to develop reusable space transportation systems, heavy lift launch, crew transfer vehicles, life support technology, and space power and propulsion systems that are needed to establish bases on the Moon and Mars.

- *How long will it take to achieve the specified goals of your option?*

Again, the program I have outlined is not a "goal," it is a way of life, an essentially permanent part of our nation's technical, cultural, political and, yes, budgetary landscape. We will achieve important intermediate milestones, such as a return to the Moon, the first landing on Mars, and many other uplifting events. But one has only to fly over the United States from coast to coast to realize that, in a very real sense, the "settlement" of the America is hardly complete, even after five hundred years of European presence in the Americas. The settlement of the solar system can be expected to take a bit longer.

The required time to achieve the intermediate milestones is irrevocably tied to funding constraints. If no new funding can be provided, we will spend the next several years—probably a decade—working our way out of the Space Shuttle and International Space Station dilemmas, even proceeding as expeditiously as possible. It will be difficult, likely impossible, to begin development of (for example) heavy lift launch vehicles and space nuclear power systems while restricting NASA to today's budget levels and simultaneously respecting current obligations to ISS. Yet, these technologies and others are crucial to any permanent step beyond LEO. There is a lot of ground to be made up, but with a $5 B annual funding increase for NASA, I believe one could expect to see the first lunar base within a decade.

What is needed is a different view of space flight in the affairs of men and nations than we have so far seen. Space programs in the United States have so far have been just that—programs. They are justified individually, each on its own merits, and have defined goals, funding, start dates and, it is hoped, completion dates. Space activities so far have been largely episodic, when in fact they need to become, again, a way of life.

NASA and the space community generally, whether civil or DOD, receive frequent criticism for the high cost of what we do, the cumbersome pace at which it often seems to proceed, and the not infrequent failures which occur. This may not be entirely unfair; it is my own belief that the Nation is entitled to expect a higher standard of performance on space projects than has often been the case in recent years. But we in the space community—the engineers who must execute a multi-year vision one budget year at a time—are, I think, entitled to expect a higher and more consistent standard of commitment by the Nation, through its policy-makers, to that vision.

As an example of the mindset I advocate, I note that the United States has a Navy, which institution in fact predates our present form of constitutional government. Even in difficult times, we do not debate whether or not the United States will continue to have a Navy. We do not debate the Navy's function; by common understanding, it is the Navy's purpose to provide mastery and control of the high seas for the benefit of the Nation. We may debate ways and means of achieving this, but withdrawal from the basic enterprise would be unthinkable. So it must be with human space flight. We are not yet to that point.

- *What technical hurdles must be overcome in pursuing the option, and what steps that must be taken to overcome those hurdles? Are there intermediate program goals, and when might these be achieved?*

I will comment on specific technical issues below, but before so doing I feel compelled to note that the technical challenge does not seem to me to be the biggest problem we have. We did not retreat from the Moon because of technical difficulties, we did not fail to go to Mars because of technical problems, and we have not taken twenty years to put a space station in orbit because of technical matters. In each case the issues are matters of politics and leadership. Without a bipartisan, leadership-driven consensus that a vigorous space exploration program is essential to America's future, we will not have such a program, whether or not there are technical challenges to be overcome. It has been forty years since a Chief Executive has propounded such a vision, and no Congress has ever taken the initiative to do so. If the Nation's leaders cannot say that space exploration is important, and why, it will not occur.

And technical challenges do exist. They include both human and engineering elements. We have considerable experience in the microgravity environment, and some practical and effective countermeasures have shown promise in minimizing bone loss, though more work is clearly needed. The most practical long-term microgravity countermeasure may well be to design our spaceships to supply artificial gravity by spinning them to generate a centrifugal force. Planetary surfaces are another matter. We have at present no clear understanding of how the human organism will respond and adapt to fractional gravitational environments such as will be experienced on the Moon and Mars. The most difficult issue is likely to be that of cosmic heavy-ion radiation. The human effects of and countermeasures for heavy ion radiation, encountered in deep space but not in the LEO environment of the ISS, have received little attention thus far.

On the engineering side, the first order of business is largely to restore capabilities that we once had, and then to make them more reliable and cost effective. It may not be impossible to consider returning to the Moon, or going to Mars, without a robust heavy-lift launch capability, but it is certainly silly. Our last Saturn V was launched thirty years ago, and while I do not necessarily advocate resurrecting an outdated design, this is the class of capability which is needed for the human space flight enterprise.

At the same time, much cargo (including humans) does not need to be launched in very large packages. We desperately need much more cost effective Earth-to-LEO transportation for payloads in the size range from a few thousand to a few tens of thousands of pounds. In my judgment, this is our most pressing need, for it controls a major portion of the cost of everything else that we do in space. Yet, no active U.S. government program of which I am aware has this as its goal.

As I have tried to indicate earlier, it is very difficult to comment on the nature and timing of intermediate program goals and milestones without reference to funding constraints.

For interplanetary flight, something more than chemical propulsion is clearly needed for other than return to the Moon or, possibly, the first expeditions to Mars. Nuclear propulsion makes the most sense to me; several options are available, including both nuclear-thermal and nuclear-electric concepts. We once had an operating, ground-tested (though not flight-tested) nuclear-thermal upper stage intended for use on the Saturn V. The program was canceled thirty years ago, when it became clear that a Mars mission was not in the Nation's immediate future. Numerous nuclear fusion concepts potentially applicable to space propulsion exist, most notably those involving electrostatic confinement of the nuclear core, but none of these is receiving more than token funding. There also exist a number of promising approaches to electric propulsion, notably the Vasimir engine concept. In the long run, some form of nuclear-electric propulsion is likely to offer the best combination of efficiency and packaging capability for interplanetary flight.

- *What is the implication of this option for the current human space flight program? To what degree does the current human space flight program contribute to or impede the option you suggest? What recommendations do you have for the Space Shuttle and International Space Station programs?*

I have alluded above to some of the technical hurdles that we face in a commitment to a permanent program of human space exploration. Broadly, the tools necessary for this enterprise include:

— Heavy-lift launch capability, in the 100 metric ton to LEO class or greater.
— Reliable, efficient, and cost effective transportation to LEO for moderate size payloads.
— Compact space qualified nuclear power systems.
— Nuclear and nuclear-electric upper stage vehicles for application to interplanetary flight.
— Space and planetary surface habitat and human suit technology.
— Technology and systems for utilizing the *in situ* resources of the Moon, Mars, and asteroids.
— Reliable and routine Earth-to-LEO crew transfer systems.

These are the things we would be working on, and would have been working on for decades, had we a consensus that the primary purpose of the Nation's human space flight program was to begin the exploration of the solar system. The fact that we are largely *not* allocating the human space flight portion of the NASA budget to these tasks illustrates more plainly than any rhetoric that our space flight programs are directed to no useful end.

I will repeat only briefly my remarks above concerning ISS; we should do what is necessary to bring the program to an orderly completion while respecting our international partnership agreements, obtaining where possible as much scientific value as we can from the enterprise while accommodating ourselves to the fact that such value is inevitably limited.

Regarding the Space Shuttle, I have previously offered my opinion to this committee that we should move to replace this system with all deliberate speed. While the Shuttle's capabilities are extensive and varied, it has proven to be extremely expensive to use, unreliable in its logistics, and operationally fragile. It is extremely risky for the crews who fly it because, while its mission reliability is no worse than other launch vehicles, there is seldom any possibility of crew escape in the event of an anomaly. The Shuttle has met none of its original goals, despite the best efforts of some of our nation's best engineers to achieve those goals. Neither NASA nor the Nation as a whole saw, or could see, these problems looking forward in

1972, when the Shuttle program was approved. But, three decades later, I think we must admit to ourselves that it is time to move on.

BIOGRAPHY FOR MICHAEL D. GRIFFIN

Michael D. Griffin is President and Chief Operating Officer of In-Q-Tel, the independent, nonprofit venture group chartered to identify and invest in cutting-edge commercial technologies for CIA and other intelligence community applications.

Mike was previously CEO of the Magellan Systems Division of Orbital Sciences Corporation, and also served as General Manager of Orbital's Space Systems Group and as the company's Executive Vice President/Chief Technical Officer. Prior to joining Orbital, he was Senior Vice President for Program Development at Space Industries International, and General Manager of the Space Industries Division in Houston.

Mike has served as both the Chief Engineer and the Associate Administrator for Exploration at NASA, and as the Deputy for Technology of the Strategic Defense Initiative Organization. Before joining SDIO, he played a leading role in numerous space missions while employed at the Johns Hopkins Applied Physics Laboratory, the Jet Propulsion Laboratory, and Computer Sciences Corporation.

Mike holds seven degrees in the fields of Physics, Electrical Engineering, Aerospace Engineering, Civil Engineering, and Business Administration, and has been an Adjunct Professor at the George Washington University, the Johns Hopkins University, and the University of Maryland. He is the lead author of over two dozen technical papers and the textbook *Space Vehicle Design.* He is a recipient of the NASA Exceptional Achievement Medal, the AIAA Space Systems Medal, and the DOD Distinguished Public Service Medal, and is a Fellow of the AIAA and the AAS. He is also a Registered Professional Engineer in Maryland and California, and a Certified Flight Instructor with instrument and multi-engine ratings.

Chairman BOEHLERT. Thank you very much, Dr. Griffin.

Dr. Huntress.

STATEMENT OF DR. WESLEY T. HUNTRESS, JR., DIRECTOR, GEOPHYSICAL LABORATORY, CARNEGIE INSTITUTION OF WASHINGTON

Dr. HUNTRESS. Mr. Chairman, Members of the Committee, I am grateful for this opportunity to testify before you today on my view of the future of this planet's human space flight program. I believe that the American public wants an adventurous space program to new, exciting destinations in the solar system and beyond.

The challenge is to move outward beyond the Earth to these exotic places, places where we have been given tantalizing glimpses from our robotic exploration program. The Shuttle and the Space Station are the legacy of a long-past era in which the space program was a weapon in the Cold War. The *Apollo* program was not primarily the science or exploration program we are all fond of remembering, it was a demonstration of the power and national will intended to win over the hearts and minds around the world and to demoralize the Soviet Union. Exploration is not what motivated Kennedy to open the public purse. Beating the Russians did. *Apollo* accomplished that and the Nation moved on to other priorities, which did not include what the space enthusiasts and much of the public thought would happen, lunar bases or on to Mars.

The imperatives are very much different today. Three decades of wishful thinking and building space ambitions on an inadequate funding basis has led us into a blind alley. The Space Station was not the expected transportation mode for missions beyond the Earth that it was supposed to be. It has become an Earth orbital end unto itself. The Space Shuttle is not the low-cost, low-risk operational space transportation system that it was supposed to be.

I think that the legacy of the *Columbia* accident should be to create a new pathway and a sense of purpose for human space flight. And if space explorers are to risk their lives, they should do so for challenging reasons, such as exploring the Moon, Mars, asteroids, and for constructing and servicing space telescopes. The whole point of leaving home is to go somewhere, not to endlessly circle the block.

What the public wants is clarity of purpose. A Space Station advertised as "the next logical step" without filling in that blank "to what" just doesn't do it. There is a growing consensus that a coherent vision for human space flight over the next several decades is required, one that has a clear sense of purpose and destination.

Sooner or later we have to have a clear destination or human space flight won't survive and America will be much the poorer for it. A new option doesn't have to be funded like *Apollo*. It can proceed at a steady pace. The country needs the challenge of grander exploration to justify the risk and to lift our sights, to fuel human dreams, and to advance human discovery and knowledge. We need to go somewhere.

As a scientist, when I ask why we need such an enterprise, I start with very public questions, such as: Where did we come from, what will happen to us in the future? And these then define the scientific objectives required to answer them. And these objectives will determine what kind of exploration is needed and at which destinations. And my answer is there are four: the Sun-Earth Lagrangian point L2, the Moon, Near-Earth asteroids, and Mars.

Mars is the most challenging, the most distant, and the most scientifically rewarding and the one place that can galvanize human interest like no other. It is the logical destination for humans in the next step of this new century. It is the most Earth-like of all of the planets in our solar system. It may have had life early in its history. It might possibly harbor microbial life below the surface today. And one day in the future, it may become a new home for humankind. It has fascinated humans for centuries, and it is within our reach.

In pursing these destinations, do we use human or robotic missions? The answer has always been both. Both of these enterprises have coexisted and cooperated during the entire history of the space program. Science cost effectiveness is not a good metric for assessing human versus robotic modes, and human exploration of space is really motivated by a lot more than science but by more societal factors.

And a space exploration program that the public requires does want humans in space. The bottom line is the human space flight program needs to be set on a new path that leads to a future that the public has been expecting for decades, a path that takes humans beyond orbit to new important destinations.

We need a national vision that sets a destination for human exploration and that systematically pursues its fulfillment with both robotic and human space flight.

Thank you for your attention.

[The prepared statement of Dr. Huntress follows:]

PREPARED STATEMENT OF WESLEY T. HUNTRESS, JR.

Mr. Chairman and Members of the Committee:

Members of the Committee, I am grateful for the opportunity to testify before you today on my view of the future of this planet's human space flight program. On April 3, 2001, I testified before your Subcommittee on Space and Aeronautics on this same subject. The views I expressed at that time have only become stronger. The public wants an adventurous space program, a Mission From Planet Earth to new exciting destinations in the solar system and beyond. The public wants to know where we are going, how we are going to get there and wants to go along for the ride even if only virtually. America has the right stuff, but today's human space flight program isn't giving the public what it wants.

Old Legacies

The challenge for NASA is to throw off the yoke of the *Apollo* program legacy and to move outward beyond Earth to exotic places in the solar system, those places where we have been given tantalizing glimpses from our robotic exploration program. The Shuttle and Space Station are the legacy of a long-past era in which the space program was a weapon in the Cold War. The *Apollo* program was not primarily the science or exploration program we are all fond of remembering, it was a demonstration of power and national will intended to win over hearts and minds around the world and to demoralize the Soviet Union. Exploration is not what motivated Kennedy to open the public purse. Beating the Russians did. It worked. *Apollo* accomplished what was intended and the Nation moved on to other priorities, which did not include what space enthusiasts and much of the public thought would happen—lunar bases and on to Mars.

The Space Shuttle and International Space Station (ISS) are the products of NASA attempting over the decades to preserve the *Apollo* era of human space flight already passed by. These are complex, expensive projects that produce enormous strain on NASA's budget and corresponding stress on the heroic people who work so hard to preserve the enterprise. The current human space flight program is barely affordable with what NASA is appropriated. The *Apollo* era is gone, the imperatives for space exploration are very different now than they were in the 1960s, and three decades of wishful thinking and building space ambitions on an inadequate funding basis has led the Nation into a blind alley. The ISS is not the expected transportation node for missions beyond Earth orbit that it was supposed to be; it has become an Earth-orbital end unto itself. And the Space Shuttle is not the low-cost, low-risk operational space transportation system that it was supposed to be.

The legacy of the *Columbia* accident should be to create a new pathway and sense of purpose for human space flight. We should provide a more robust transportation system for our astronauts and a more rewarding program of exploration for these heroes. They should be assured of a reliable, safe system for transporting them a distance no farther than the distance between New York and Washington. And if space explorers are to risk their lives it should be for extraordinarily challenging reasons—such as exploration of the Moon, Mars, and asteroids, and for construction and servicing space telescopes—not for making 90 minute trips around the Earth. *The whole point of leaving home is to go somewhere, not to endlessly circle the block.*

Just as for *Apollo*, the Shuttle and ISS were developed for political imperatives; not so much for space exploration but to keep humans flying and to serve a foreign policy agenda. The Shuttle and ISS have not proven to be the next steps to human deep space exploration as advertised, instead they have become an impediment—serving only to maintain a human presence in near-Earth space until society finally decides to undertake missions to destinations beyond Earth orbit. Immediately after the *Columbia* accident, Charles Krauthammer, a noted columnist put it far better than my scientist training allows:

> "We slip the bonds of Earth not to spend 20 years in orbit studying zero-G nausea, but to set foot on new worlds, learn their mysteries, establish our presence.. . .After millennia of dreaming of flight, the human race went from a standing start at Kitty Hawk [almost exactly 100 years ago] to the Moon in 66 years. And yet in the next 34 years, we've gone nowhere.. . .For now, we need to keep the Shuttle going because we have no other way to get into space. And we'll need to support the Space Station for a few years, because we have no other program in place.. . .If we are going to risk that first 150 miles of terrible stress on body and machine to get into space, then let's do it to get to the next million miles—to cruise the beauty and vacuum of interplanetary space to new worlds. . .the problem is not manned flight. The problem is this kind of manned flight, shuttling up and down at great risk and to little end."

New Options

We have reached a point now where we reflect fondly on a time past when America shined brilliantly in human space exploration, but can only lament our retreat while others climb a path we pioneered and abandoned. We can shine again. We are a wealthy and capable nation. We have the resources. The required technology is at hand or just around the corner of development. These are not the issues. The issue is national will. Space exploration has become a part of our culture. The public believes that flying in space is part of who we are as a nation. "Space exploration is an element of our national being" [Harrison Schmidt, former astronaut and former Senator from New Mexico]. Our robotic explorers generate enormous interest when they fly and land on other planets. But the public expectation is that these robotic missions are a prelude to sending humans.

What the public wants is clarity of purpose. A Space Station advertised as "the next logical step" without filling in the blank "to what" doesn't do it. There is a growing chorus of leaders inside and outside of government concerned that NASA's post-*Columbia*-investigation posture is business as usual. The consensus of many is that a coherent vision for human space flight over the next several decades is required, one that has a clear sense of purpose and destination. According to Neil Lane, former NSF Director and Presidential Science Advisor, "Unless we can get a clear, stated mission, we should step back and not risk further lives."

Sooner or later we must have a clear destination for human space flight or it will not survive, and America will be much the poorer for it. And a new option doesn't have to be funded like *Apollo*, it can proceed at a steady pace. The country needs the challenge of grander exploration to justify the risk, lift our sights, fuel human dreams, and advance human discovery and knowledge. WE NEED TO GO SOMEWHERE!

There are organizations outside NASA and the U.S. Government that are addressing this issue. The International Academy of Astronautics is conducting a study entitled "The Next Steps in Exploring Deep Space." Its purpose is to provide a logical and systematic roadmap for the long-term scientific exploration of the solar system beyond Earth orbit with a goal to land humans on Mars sometime in the next 50 years. The study will be completed this coming spring and envisions the establishment of a permanent human presence in space using an evolutionary approach to the development of space transportation infrastructure utilizing well-defined intermediate destinations as stepping-stones to Mars.

In addition, a workshop this past spring run by three organizations—The Planetary Society (TPS), the American Astronautical Society (AAS) and the Association of Space Explorers (ASE)—has made recommendations for near-term actions to solve our post-*Columbia* problems in human transportation to Earth orbit. My testimony draws heavily on the results from this joint workshop and from the IAA study. The workshop statement and a short briefing on the interim results of the IAA study are attached.

The Exploration Imperative

Fifty years ago, in 1952, we developed a national dream of space exploration. As a nation of people who make dreams happen, and who explore to provide for a better life, we didn't do too badly with making that mid-Century dream of space travel come true. But after the *Apollo* missions the dream to move on was put on hold. So why should we revive that dream to explore space in this new 21st Century? For the same reasons that we explored and developed air travel in the 20th Century. Because it challenges us! At the beginning of the 20th Century in America the great public adventures were exploration of the polar regions of Earth and powered flight through the air. A century later, millions of humans travel in comfort through the air to destinations around the planet. No one in 1900 could have dreamed it possible to fly in comfort from New York to Paris in just over six hours.

And so it will be in the 21st Century. At the beginning of this century we know how to travel in space, but are only just on its edge. We fly into space on dangerous, unwieldy, bolted-together hunks of thin metal and bulky propellant, spinning around our own planet in a fragile metal can strung together with cables and trusses. In one of history's major anomalies, we even flew men to the Moon and back 30 years ago, but are unable to do it now. By the end of the 21st Century, space travel will be as commonplace as air travel is at the end of the 20th. We just can't predict the details right now, just as the Wright Brothers could never have imagined a Boeing 747 in 1903.

Exploration and the drive to discover and understand are qualities that have allowed the humans to survive and become the dominant species on the planet. Human beings strive to know and understand what surrounds them. By exploring the unknown, humans gain security and dispel fear of the unknown, of what is beyond. This survival mechanism is encoded in our genes. Just as human civilization uses the challenge of exploration to hone scientific and technological skills for survival, and exploits the adventure to provide hope for the future, human populations also have a need for heroes to provide inspiration. This is particularly important for our youth, who need to be provided with a positive vision for their future. Every generation has had its heroes. Today, the astronaut is a hero figure because astronauts carry out adventurous work that achieves exciting goals, personifying the kind of life that our youth would like to lead. Space exploration presents a positive image of the future and inspires our youth towards achievement.

The Science Imperative

In the 1960s, the space program was popular in the U.S. because the public knew precisely what the goal was, how the game was played and followed every play. Today, the public's innate acceptance of the abstract notion of exploration as a human imperative does not necessarily extend to their checkbook without clear articulation of goals and benefits. Today the public benefit can be expressed as a clear set of goals because science and technology has progressed to the point where it can dare attempt answer some of the most burning questions that human beings have been asking since they started gazing upward at the sky. Questions such as 'Where do we come from?' and 'What will happen to us in the future?' and 'Are we alone in the Universe?' These very fundamental human questions can be recast as scientific challenges—goals to be achieved in the course of exploring space. And from these scientific goals, plans can be formulated for both robotic and human explorers including the destinations and the exploration objectives of each.

Where did we come from? This is a question that approaches the contemplation of existence. Even so, astronomers can address the question by determining how the Universe began and evolved, and learning how galaxies, stars and planets formed, and searching for Earth-like planets around other stars. The answers require large and complex space telescope systems made possible by human construction and servicing in space.

What will happen to us in the future? Every human wonders about the future. One form of this question asks if there is any threat to us from space, especially from Earth-crossing asteroids. The answer will come from surveys of the Earth-crossing asteroid population in space and space missions that determine their composition and structure. Another form of this question asks what future humans have in traveling to and living on other planets. Is our species destined to populate space? Ultimately I believe the answer is yes, and the information will come from exploring space and utilizing the resources we can find in the most promising places in space such as Mars.

Are we alone in the Universe? Every human being wants to know the answer to this question. We are compelled to find its answer. Some find comfort in the notion that we should be alone; others are fearful of the potential for other life "out there." Most scientists see the possibilities and are overwhelmed by the notion that the Universe might be teeming with life; at least microbial life and perhaps even intelligent forms. We will find the answer by searching for life in the most promising places in the solar system such as Mars, and by looking for signs of life on planets outside the solar system with space telescopes.

Destinations

The IAA study starts with these public questions and defines the scientific objectives required to answer them. The scientific objectives in turn determine what kind of exploration is required at which destinations in the solar system. Four destinations for human exploration result from this exercise: the Sun-Earth Lagrangian point L2, the Moon, Near-Earth Asteroids, and Mars.

Mars, the most distant and most challenging of these destinations, is also the most scientifically rewarding and the one place that can galvanize human interest like no other. It is the logical destination for humans in the next decades of our new century. Mars is the most Earth-like of all the other planets in our solar system. It may have had life in its early history, it might possibly harbor microbial life below its surface today, and one day in the distant future it may become a new home for human kind. It has fascinated humans for centuries and it is within our reach.

A brief description of the scientific and exploration utility of the four identified human destinations are described below, arranged in order of energetic difficulty for a systematic, progressive approach to exploration beyond Earth orbit.

Sun-Earth Lagrangian Point L2 (SEL2) is a point about one million miles from the dark side of the Earth opposite the Sun that is the site of choice for future space astronomical telescopes that will search for and image Earth-like planets around other stars. These telescopes will of necessity be large, complex systems requiring servicing by astronauts in a manner similar to the Hubble Space Telescope. SEL2 is easy to get to, with round trip times on the order of 2–3 weeks and could serve as the initial step in developing a deep space transportation capability.

The Moon is a scientifically rewarding destination where we can obtain information on the probability for impact of asteroids on the Earth, on the history of the Sun and its effect on the Earth's environment, and perhaps on the earliest history of the Earth itself. The proximity of the Moon makes it attractive as a potential proving ground for surface systems, habitats and other technologies, possibly including the use of lunar resources, but it is not necessarily on the critical path to Mars exploration.

Near-Earth Objects travel in orbits between the Earth and Mars and represent both a potential resource in space and a potential impact hazard to Earth. Robotic missions to these objects will be necessary to assess these potentials. The jury is out on whether human missions would be necessary for these purposes, but there is no doubt that a one-year human mission to a Near-Earth Object would serve as an excellent intermediate step before any mission to Mars. An NEO human mission would provide a lower-risk test flight of the systems necessary to reach Mars.

Mars is the ultimate destination for humans in the first half of this century. It is on this most Earth-like planet that humans can establish a permanent presence—utilizing resources the planet has to offer from its atmosphere, soil and subsurface ice and water. The scientific goals will be to understand the similarities and differences between Earth and Mars, particularly the history of water and its distribution on Mars, the geological and climatological histories of Mars and a search for evidence of past or present life. The question of possible life on another world is probably the largest driver for humans in space and particularly for Mars exploration.

Our ultimate ability to reach these destinations requires that architectures developed today for transportation from the Earth's surface to orbit have a top-level requirement to consider the future needs for space transportation to deep space. Otherwise, it is likely that a solution will be derived that is useless for the next step beyond Earth orbit.

The Architecture

The IAA study proposes an architecture for enabling this vision. *Mars is the goal,* but intermediate destinations are identified that comprise a progressive approach to this long-term objective. The approach is *science-based* to address key questions of public interest. These science goals provide the context for destinations, capabilities and technology investments. It is a *stepping-stone approach* in which there is a logical progression to successively more difficult destinations. This approach requires *incremental investments* to maintain progress, rather than huge new budgets, and destinations can be adjusted to manage cost and risk. Major new *technology developments* early in the program are avoided to reduce cost. Solar electric and nuclear electric propulsion, which are already under development, along with improved chemical propulsion can meet early transportation needs. *Cargo and crew are separated* to minimize crew risk and flight time. Cargo, supplies, and exploration equipment travel slower on more efficient electric propulsion systems in advance of the crew, who use faster but less efficient chemical propulsion systems.

The IAA study proposes development first of a chemically propelled Deep Space Transportation Vehicle (DSTV) initially capable of carrying astronauts from low-Earth orbit to SEL2. The DSTV would be equally capable of carrying astronauts to lunar orbit if it is decided that lunar missions are an important step toward Mars. Later this vehicle could be upgraded for the much longer trips to NEOs and Mars. A separate electrically propelled Deep Space Cargo Vehicle (DSCV) would be developed to carry equipment and supplies to these same destinations.

The IAA study does not address Earth-to-orbit infrastructure requirements. This has been done by the TPS/AAS/ASE workshop that recommends the retirement of the Shuttle after the ISS has been completed. Both the IAA study and the TPS/AAS/ASE workshop recognize the potential of utilizing non-U.S. launch systems to carry crew and cargo to low-Earth orbit. In addition, new vehicles for Earth to orbit transportation, separating crew from cargo, would be developed that take into account crew and cargo Earth-to-orbit lift requirements for further exploration beyond Earth orbit.

The Space Station is not on the critical path in the IAA transportation architecture. Its high inclination orbit creates a severe penalty for Station-launched missions to the Moon and planets. However, the Space Station is required in order to study the effects of space travel on humans and to develop the technologies required for human support during long-term space flight.

Robots and Humans

So how do we implement such a plan, do we use human or robotic missions? The answer has always been: both. The robotic and human space exploration enterprises have co-existed and cooperated during the space program's entire history. The relevant question is whether any potential investigation requires using human explorers, with their associated cost. The argument often used to dismiss humans is that technology will produce a machine with sufficient intelligence and dexterity to render a human unnecessary. The time to develop such a machine, however, may be either unpredictable or too long to meet a reasonable schedule. No matter how clever or useful the robots we make, they will always be tools for enhancing human capabilities.

There is a role for both robots and humans. The strategy is to use robotic means for reconnaissance and scientific exploration to the full extent that robots can accomplish the desired goals. At the point when human explorers are sent, robotic missions can be used to establish local infrastructure before the arrival of humans. This is implemented using robotic outposts, which are later occupied and utilized by the human explorers. During human occupation, robots provide required support services and become sensory extensions and tools for human explorers.

In any case, science cost effectiveness is not a good exclusive metric for assessing human vs. robotic modes for scientific exploration because the decision to proceed with human exploration will not be made on scientific grounds alone. Human exploration of space is motivated by societal factors other than science. Nonetheless, when a decision is made to continue human exploration beyond Earth orbit, it will provide a tremendous opportunity for scientist-explorers and science should be a motivating force in defining human space exploration goals.

A space exploration enterprise that satisfies the public requires humans in space. In the minds of the public, robotic exploration is an extension of the human experience and a prelude to human exploration itself. Robotic exploration is the method of choice for reconnaissance and scientific investigation to the extent that robots can accomplish the desired goals. However, only human explorers will ultimately to fulfill the public's sense of destiny in space.

The Bottom Line

The human space flight program needs to be set on a new path that leads to a future that the public has been expecting for decades—a path that takes humans beyond Earth orbit to new, important destinations in the solar system.

WE NEED A NATIONAL VISION THAT SETS A DESTINATION FOR HUMAN EXPLORATION AND SYSTEMATICALLY PURSUES ITS FULFILLMENT WITH BOTH ROBOTIC AND HUMAN SPACE FLIGHT.

Drawing heavily on the IAA study, I believe this vision should involve:

1. The goal of establishing a permanent human presence in the solar system with the stated objective to establish human presence on Mars by the middle of this Century.
2. Recognition that exploration beyond Earth orbit is intrinsically global, and should involve cooperation with other space-faring nations.
3. A progressive, step-by-step approach for human exploration beyond Earth orbit that does not require an *Apollo*-like spending curve. Any requirements for increased spending can then be made incrementally on an annual basis.
4. A set of exciting and rewarding destinations in this step-by-step approach to Mars including the Sun-Earth Lagrangian Point L2, the Moon and Near-Earth Asteroids.
5. Re-invention of our Earth-to-orbit transportation and on-orbit infrastructure to support the goals for exploration beyond Earth orbit. The current Space Shuttle and International Space Station are not on that critical path other than research on human physiology in space.
6. Development of new in-space systems for transporting humans and cargo from low-Earth orbit to deep space destinations. No large technological breakthroughs are necessary.
7. Continued use of robotic missions for scientific research and preparation for future human flights. Robotic precursor missions will be required to reduce the risk for human explorers and to provide on-site support for humans. Human explorers will be required for intensive field exploration and for in-space servicing of complex systems.

Drawing heavily from the TPS/AAS/ASE workshop, some near-term actions to enable this policy (specifically Number 5 above) are:

1. The Shuttle should be retired after flying only those missions necessary to complete the International Space Station in favor of a simpler, safer and less costly system for transporting humans to and from Earth orbit.
2. Human transport to and from space, and within space, should be separated from related cargo transport. New Earth-to-orbit transportation systems for humans and cargo should be designed and built, but not until the requirements for human exploration beyond Earth orbit are understood and can be accommodated.
3. The U.S. should carry out its obligations to its international partners to complete the International Space Station. The goals of the ISS should be refocused to those specific purposes required to enable human exploration beyond Earth orbit.

None of this will happen if we go on as we are. The national will to carry out a new option for space exploration already exists in the people of the United States. The Nation has the necessary wealth. It is only a matter of leadership by the Administration and Congress. The architecture advocated here does not require an immediate large increase in the NASA budget. It does require a commitment to the resources required as the space program gradually and systematically increases in scale and scope, but not so much in any one year as would be required for an *Apollo*-like initiative.

WE NEED A COMMITMENT FROM THE ADMINISTRATION AND CONGRESS TO A MANIFEST DESTINY FOR AMERICA IN SPACE.

BIOGRAPHY FOR WESLEY T. HUNTRESS, JR.

Dr. Wesley T. Huntress, Jr., is Director of the Geophysical Laboratory of the Carnegie Institute of Washington. Dr. Huntress joined the Carnegie staff in September 1998 after a 30-year career as a scientist and administrator in the Nation's space program. At the Geophysical Laboratory he directs one of the Nation's most prestigious scientific establishments in the geosciences. Dr. Huntress continues his research at GL in astrochemistry and remains a community leader in the scientific exploration of the solar system.

Dr. Huntress earned his Bachelor of Science degree in chemistry from Brown University in 1964 and his Ph.D. in Chemical Physics from Stanford University in 1968, after which he joined the science staff at Caltech's Jet Propulsion Laboratory. Dr. Huntress left JPL in 1988 to join NASA Headquarters in Washington, DC, where he served the Nation's space program for ten years. From 1988 to 1990 he was assistant to the Director of the Earth Sciences and Applications Division, from 1990 to 1992 he was Director of the Solar System Exploration Division and from 1993 to 1998 he served as NASA Associate Administrator for Space Science.

At JPL, Dr. Huntress participated in several missions, as a co-investigator on the Giotto Halley Comet mission, coma scientist for the Comet Rendezvous Asteroid Flyby mission, and as pre-project study scientist for the Cassini mission. He also served in a number of line and program management assignments at JPL. Dr. Huntress and his research group at JPL gained international recognition for their pioneering studies of chemical evolution in interstellar clouds, comets, and planetary atmospheres. Dr. Huntress's last year at JPL in 1987–1988 was spent as a Visiting Professor of Cosmochemistry in the Department of Planetary Science and Geophysics at Caltech. In 1999 the Director of JPL appointed Dr. Huntress to the position of Distinguished Visiting Scientist at JPL.

As Associate Administrator for Space Science at NASA Headquarters, Dr. Huntress was a key architect of the "smaller, faster, cheaper" mission model, and opened up new opportunities for space scientists and industry through new and innovative methods for carrying out Space Science missions. Dr. Huntress created a new, scientifically integrated Space Science program with a clear strategic vision for the future and a new strong emphasis on technology development. In carrying out this strategy, Dr. Huntress is responsible for starting a number of new missions lines including the New Millennium technology flight test program, a restructured Explorer program, the Discovery program of low-cost planetary missions including the Near-Earth Asteroid Rendezvous and Mars Pathfinder missions, the ongoing Mars Exploration Program, and Solar-Terrestrial probes series. Dr. Huntress is also the architect of NASA's new Origins program featuring new technology development in spacecraft and science instrument technologies and approvals for new space science missions such as the Next Generation Space Telescope, the Space Interferometer Mission and the future Planet Finder. Dr. Huntress is the founder of NASA's Astrobiology program.

Dr. Huntress is the recipient of many NASA awards including the NASA Exceptional Service Medal in 1988, the NASA Outstanding Leadership Medal in 1994, the NASA Distinguished Service Medal in 1996 and 1998, and the Robert H. Goddard Award in 1998. The President has honored Dr. Huntress three times, as Presidential Meritorious Executive in 1994, as Presidential Distinguished Executive in 1995 and a Presidential Award for Design of the Mars Pathfinder Mission. Dr. Huntress was awarded the Schreiber-Spence Award in 1997 for contributions to space technologies and applications. In 1998, the minor planet 1983 BH was renamed 7225 Huntress on the occasion of Dr. Huntress's departure from NASA.

Dr. Huntress is a Fellow and Past President of the American Astronautical Society and recipient of the Society's Carl Sagan Memorial Award for achievement in astronautical science. He is also a member of American Astronomical Society/Division of Planetary Sciences, current Vice-Chair, and recipient of the Division's Harold Masursky award for service to the planetary science community. Dr. Huntress is an Academician in the International Academy of Astronautics. He is also President of The Planetary Society.

Dr. Huntress currently resides with his wife Roseann in Rockville, Maryland. They have one son, Garret, an undergraduate at the University of Maryland in Computer Science.

Chairman BOEHLERT. Thank you very much, Dr. Huntress.
Dr. Koss.

STATEMENT OF DR. MATTHEW B. KOSS, ASSISTANT PROFESSOR OF PHYSICS, COLLEGE OF THE HOLY CROSS

Dr. KOSS. Mr. Chairman, Members of the Science Committee, thank you very much for inviting me to address you here today. I am honored by your request.

Like many Americans, I sat riveted to the television station that Saturday morning when the Space Shuttle *Columbia* and her crew failed to return home. I was stunned and saddened, and I was left wondering, "How could this have happened?"

As a scientist, I have participated in three of *Columbia*'s previous missions. I have worked with several of *Columbia*'s crew on their previous missions. I felt a special kinship to the *Columbia* and her crew. In a curious way, I felt that the *Columbia* was my Shuttle, and so it was a deeply shocking experience to watch the television that morning. But then another feeling sort of occurred to me. I ended up asking myself, as a scientist who had participated in these missions, in these dedicated science missions, was I, in any way, responsible for what had happened. And I feel I was, in some way, responsible. I was part of the larger NASA culture that contributed to these missions.

I was responsible for not saying what I had known privately and I had discussed with other scientists, and that is that we did not need human beings to assist in the exercise of these physical science experiments. They ran well autonomously. I had worked with NASA. I had been charged by NASA to build and test autonomous and remote controlled systems, and they had worked flawlessly. And although I had presented papers and talked about how successful autonomous programs were, I never connected the dots and said, "Well, maybe we should reconsider the use of humans in space."

I feel now that almost all of the physical science experiments that are performed on orbit could be done autonomously or remotely. I think the *Columbia* Accident Investigation Board has it right. Not only should we reverse the burden of proof in terms of not requiring that someone show that the Shuttle is not safe to fly but requiring that it is affirmatively proving that it is safe to fly. I think the science experiments need the same exact standards. If there is a science experiment that needs human involvement, the scientists backing that program need to have a preponderance of evidence that says so.

If there—however, if there were no access to the Space Station or Space Shuttle, vital research in material science would be halted. It would not necessarily be halted forever, but it would certainly be halted, and there would be an interim period. And I believe the same could be said for other sciences in the physical science portfolio at NASA.

At present, there are simply no alternatives to those platforms. I have heard a free-flyer or an autonomous platform discussed, but I don't believe there is any commitment to it at this time.

I don't have the necessary expertise or financial knowledge to give you a detailed estimate of building that—what that facility would cost. I am an assistant professor at a small liberal arts college. I clearly don't know very much about money. I do know something about the trade-offs that would occur if one developed an autonomous program. And when I look at all of those trade-offs in sum total, I reach the conclusion that the trade-offs favored the development of an autonomous platform or remote platform for orbital physical science experiments.

It is unlikely that these larger missions that my fellow panelists are talking about would help the physical sciences on-orbit program. These sciences that I represent or that I know about are laboratory sciences that are really concerned with the inner workings of, let us say, materials. I support a future manned program, it just is not to the betterment of the science I am currently pursuing.

I think NASA has the skills to develop an autonomous program. I think it is important that they do. And I would like to see that happen.

Again, I thank you for your invitation to address you here today.

[The prepared statement of Dr. Koss follows:]

PREPARED STATEMENT OF MATTHEW B. KOSS

Abstract

As a scientist whose experiments were carried out on three missions of the Space Shuttle *Columbia,* I have now concluded that the vast majority of scientific experiments conducted in orbit—including my own—do not require astronauts. The main reason for in-orbit experimentation is to significantly reduce or eliminate gravity-driven influences to better observe and understand the fundamentals of important scientific processes. But almost all of these tests, save those that must be done on human subjects, can be controlled autonomously via computer or remotely from the ground. Scientific experimentation in space can be safer and more cost effective using long-duration autonomous or remotely controlled orbital spacecraft. At the outset, the costs of developing this technology may appear greater than that of human tended experiments. But if you do not need to provide a safe and sustaining environment for astronauts the overall cost will be significantly reduced. We may always need astronauts to assume certain risks for the human exploration and development of space. However, the time has come to decouple the human exploration and development of space from the needs and benefits of conducting basic research in the laboratory physical sciences in low-Earth orbit. Doing so will benefit both the future of human space flight and the portfolio of basic research on orbit.

Introduction

Mr. Chairman and Members of the Science Committee:

Thank you for the invitation to come before you and participate in this hearing on the Future of Human Space Flight. I am honored by your request.

Like many Americans, I sat riveted to the television that Saturday morning when the Shuttle *Columbia* and her crew failed to come home safely. I was both stunned and saddened as I sat and watched and wondered, "How could this have happened?"

As a scientist, I have participated in research experiments that flew on three of *Columbia*'s previous flights (STS–62 in 1994, STS–75 in 1996, and STS–87 in 1997), and thus I felt a special kinship to the *Columbia* and her crew. In a curious way, I felt that the *Columbia* was my Shuttle. I had briefed and spoken with the crews of the three *Columbia* missions that I had worked on, and in doing so I had met Kalpana Chawla one of *Columbia*'s crew members who had just perished. I felt great sadness and sympathy for the families of the astronauts who died.

As I continued to watch the news coverage of the unfolding tragedy, I began to feel growing remorse and personal responsibility. STS–107 was a dedicated science mission, much like those in which I had participated. I asked myself if I, as a participating scientist in prior dedicated science missions, was in any way responsible for what had just occurred.

I thought back to my own time at the Marshall Space Flight Center in Huntsville, Alabama. While monitoring and controlling my experiments, my colleagues and I spoke often of the extraordinary risks that the Shuttle astronauts took each time they flew a mission. We knew that the astronauts understood the risks and accepted them willingly. As scientists, we believed we understood the risks, and we debated whether or not we bore any responsibility for the acceptance of those risks. Even though our experiments were part of the payload brought to orbit by the crew, and served as partial justification for the mission, we confidently concluded that we were not responsible for any of the risk. We reasoned that NASA created and maintains the Shuttle program in support of NASA's larger mission for the human exploration and development of space and not solely for the performance of laboratory science on orbit. Therefore, we concluded that we could not be responsible for the risks assumed.

Although our reasoning then may have been correct technically, our confident conclusion now seems utterly reckless and shamefully inadequate. That convenient, yet obviously hollow reasoning came crashing down to Earth with the *Columbia* last February. As I sat and I watched, I realized that I must bear my share of the responsibility for the *Columbia* accident.

Unlike the astronauts who either conduct or bring these experiments to orbit, scientists like me, with the exception of a few Payload Specialists, never put their own lives on the line for the work that they do or the rewards that can follow a successful experiment. Is this then the source of the scientist's culpability that we reap the rewards while standing on the shoulders of others who assume the risks? No, I think not. The scientist's culpability stems from a conceit that we have long acknowledged privately but have not expressed publicly:

> *The vast majority of physical science experiments conducted in orbit simply do* not *require on-board human intervention or assistance.*

As penance for quietly accepting the benefits of on-orbit experiments without sharing the risks or expressing the alternatives, I need to say publicly that the cost of using astronauts to perform science experiments in space is too high both in dollars spent and in lives lost. At the risk of incurring my colleagues' wrath, I feel compelled to say that I, and the other scientists who reveled in the glory of conducting experiments aboard the Shuttle, are not blameless. In that spirit, I wrote an article that subsequently appeared as an op-ed in the *New York Times* on Sunday, June 29, 2003 (see Exhibit 1, attached hereto).

Since the publication of that article, I have heard from many of my colleagues, both within and outside of NASA. Most of my fellow scientists who responded expressed their support and agreement with my article, but not all. I have engaged in lively discussions with many who have disagreed with the opinions I expressed in my article, and through those discussions, we are finding and forging common ground. My testimony here today has benefited from these discussions.

Answers To Specific Questions Submitted By the Chair

- *How necessary is it to have the participation of people in space for successful research in materials science?*

There are two types of on-orbit laboratory science experiments performed on the Shuttle: (1) payload experiments and (2) laboratory experiments. Payload experiments are self-contained packages mounted in the payload bay of the Shuttle. They run autonomously or are controlled remotely from the ground by the scientists and engineers who designed and built them. No human intervention is required for payload experiments. By contrast, laboratory experiments are conducted in the middeck or Spacelab module, and were generally operated by astronauts with teleoperational assistance from scientists on the ground.

Of the two varieties of experiments, payload experiments tend to be larger, more ambitious and robust, and historically delivered more useful data and results. Astronauts have limited time and capabilities to conduct elaborate experiments in space.

Although rarely the subject of popular media, most of the experiments in materials science conducted on orbit were payload experiments. This simple and irrefutable fact demonstrates that it is not necessary to have human participation to conduct orbital research in materials science.

While I do not profess to be an expert in fields other than my own, it follows that human participation has not been and is not essential to conduct orbital research in Fundamental Physics, as the majority of those experiments were conducted as payload experiments. In addition, and despite that the majority of experiments in both Fluids and Combustion were not conducted as payload experiments, I believe that the participation of people in space is not strictly necessary to conduct orbital research in either of these disciplines.

- *What proportion, if any, of the experiments now conducted on the Space Shuttle or Space Station unmanned probes could conduct autonomously?*

There are very few science experiments, save those on human themselves, that were conducted on the Space Shuttle or Space Station that could not have been conducted autonomously or remotely. At the outset, making on-orbit experiments fully autonomous or remote controlled will require more development time, and the experiment design would most likely need to be more complicated and involved, but it can most certainly be accomplished. Speaking immodestly, scientists and engineers are a creative and gifted bunch and are more than up to the task of finding new ways to conduct orbital research without on-site human assistance.

Nonetheless, with apologies to the Committee, I respectfully submit that we are asking the wrong question. The *Columbia* Accident Investigation Board concluded that the burden of proof must be reversed on any future Shuttle missions. Instead of awaiting evidence that the Shuttle might be unsafe to fly, on any future missions, NASA must instead affirmatively demonstrate that the Shuttle is safe to fly. Given the grave risk to human life orbital research involves, scientific experiments ought to meet that same exacting standard. If a scientist proposes an orbital experiment to be conducted by astronauts aboard the Shuttle or the Space Station, he or she must demonstrate by a preponderance of evidence that human assistance is only reasonable way to conduct the given experiment.

Although some may believe me audacious for making such a sweeping statement, I submit here today that almost all the physical science experiments now conducted on the Space Shuttle or Space Station could be conducted autonomously or remotely. In addition, I believe that many life science experiments, save those using human themselves as subjects, could be conducted autonomously or remotely as well.

I have made a broad and bold assertion, and one that requires some additional explanation. To do that, let's imagine a hypothetical "experiment" where we want to compare how water and milk freeze in ice cube trays. The easiest way to proceed is to get a freezer, some ice cube trays, a camera, some thermometers, and a computer. Then, one after another, fill the ice-cube trays, place them in the freezer, and record what happens. This is simple, fast, and completely human dependent. If we were to repeat this experiment in a dangerous environment, the needs and requirements of the human operator to exchange the ice cube trays would be a major concern and complicating factor. If we were to repeat this imaginary experiment on orbit, the human operator is placed at extreme risk, and at a minimum requires significant infrastructure and support. In this imaginary experiment, the ease of conducting the experiment via human operators is clearly offset by the complexities and risk of getting the operators safely to orbit and back, and of sustaining them while in orbit. The added complexities, development time, expertise and effort to automate or remotely control the exchange ice cube trays and the recording of data is quite obviously the best way to proceed. This is very much the situation we are in with respect to human enabled experiments on the Space Shuttle or Space Station.

In the case of the Space Shuttle and Space Station, the infrastructure and facilities to support humans on orbit is already there. So it is certainly easier to design smaller experiments to operate in the laboratory mode with astronauts running experiments that are important and compelling. However, this is an efficacy and not a requirement. With sufficient development time, funding, and expertise, virtually all physical science experiments now conducted on orbit could be done either autonomously or remotely. In addition, doing so would be consistent with the *Columbia* Accident Investigation Board's recommendation to separate humans from cargo.

It is easy to imagine the criticisms to this analysis from those who believe that direct on board human engagement is required. They might say that intelligent response is required to deal with unanticipated phenomena, or that a particular instrumental dexterity is required, or that humans are needed to troubleshoot and repair instruments and equipment, or that we need human involvement to realize serendipitous discoveries. To be sure, all of these criticisms have an element of truth, but in the end, they do not withstand detailed scrutiny.

The creative input of human intelligence to deal with unanticipated phenomena is a hallmark and a necessity of experimental science. Indeed in many experiments there will be contingencies that were not preprogrammed into an automated system. However the remote control of orbital experiments provides the necessary human intervention. The scientists on the ground who are most expert in the phenomena and the experimental apparatus are the most qualified to recognize the need for change, and to make that change. If a hardware or equipment modification is now called for, then a re-flight is the best way to make that modification.

For the issue of instrumental dexterity, clearly humans are better at some tasks while computer or technology is better at others. However in experimental science there is no single correct way to accomplish a particular task. There are many ways that work and the job of the experiment designer is to find a way that works. That way may require the unique abilities or advantage of a human operator and may indeed be the simplest and most straightforward way to accomplish a particular task. However it is extraordinarily unlikely that it is the only way. The challenge of the design team is to figure out a way to accomplish the task that does not require human dexterity.

Troubleshooting or repair of apparatus and equipment is most definitely an area where humans excel as compared to autonomous or remote control systems. However I know of no experiment so important that it is required that it be successful on the particular flight it is manifested. It seems to me that in such cases where repair is necessary, that the repairs could take place post flight and the experiment could be re-manifested and flown in due course.

Advocates for an on board human role in physical science experiments often claim that the serendipitous discoveries that are vital to the continuing advancement of science require a human being with all five senses activity involved in the experiment. I certainly agree that serendipitous discoveries are vital to a healthy science. Today's directed research questions often came from yesterday's serendipitous discovery. However the key to these discoveries lies in the mind of the scientist and not in the sense instruments. In addition, who is more likely to make a serendipitous discovery? The astronaut, who no matter how extraordinary, or well trained, has many experiments and tasks to monitor and is not an expert in the particular experiment. Or the science team on the ground comprised of the experts who designed the experiment and are engaged with the tele-metered data full time? Clearly the scientists on the ground are better prepared to make serendipitous discoveries.

In addition, of the five human senses, only taste and smell cannot be bettered via instruments. We certainly don't want astronauts using their sense of taste or smell in performing experiments on orbit. To protect the astronauts, we rightly require that every experiment be carefully contained and confined to ensure no breeches or leaks that could be inhaled or ingested. Furthermore, the apparent weightless environment affects the astronaut's sense of smell and taste and serendipitous discoveries come from the superior sensitivity of cameras and sensors that record precise data at high data rates. Thus, many of the subsequent unanticipated discoveries come later, and these discoveries are made by the science teams who even years later are still studying and analyzing the data from a flight experiment.

To be sure, with a broad and sweeping statement such as "almost all the physical science experiments now conducted on the Space Shuttle or Space Station could be conducted autonomously or remotely" there will be exceptions. I thank the many scientists who took the time to discuss their concerns with me following the publication of my article. However, because I believe these situations will be the exception rather than the rule, it goes without saying that we need a well-designed rubric to determine when an exception is warranted even if it has been demonstrated with a preponderance of evidence that human tending is absolutely required.

First, is there sufficient probable value in the results of the given experiment? If it were probable, or even reasonable possible, that the human tending of a given experiment would yield key or irreplaceable results on the path to curing cancer then that experiment would be worth the established costs and risks. For such a seminal experiment even I would be able to overcome my fear of flight to participate in such an endeavor. However, revolutionary results of that dimension are extraordinarily rare in science and should not be the basis of policy. Science grows and develops by innumerable small and hesitant steps, and its power comes from, as the great philosopher of science Alfred North Whitehead said, ". . .the entire transformation of human habits and human mentality produced by the long line of men of thought from Thales to the present day, men individually powerless, but ultimately the rulers of the world."

Second, as discussed above, scientists must be made to demonstrate that human tending of their experiment is vital to the success of their experiment. Put bluntly, the experiments of scientists who are unwilling or unable to state why their experiment could not be designed to run autonomously or remotely ought to not receive access to precious orbital research time, money, and space. Or alternately they affirm that the flight and the risk are bourn for other reasons and the human tended science experiment is a valuable add on. As the *Challenger* and *Columbia* tragedies have made all too apparent, science must be accountable for the high costs and substantial risks human-tended experiments entail. We scientists should no longer be given a free ride on these issues.

This very change in philosophy of on-orbit scientific pursuits has already begun in the field of astronomy. NASA has chartered a panel to review agency plans for the phase out of the Hubble Space Telescope to the transition to James Webb Space Telescope. The Hubble Space Telescope however could still be further enhanced and its life extended by Space Shuttle servicing missions. Naturally such missions are both risky and expensive. Not being an astronomer, I take it as axiomatic that such missions would significantly contribute to astronomy, and that in any reasonable near-term such a mission could not be conducted robotically or remotely. The question then that the panel must answer and take ownership of is "is the further enhancement and use of the Hubble Space telescope worth the risk and the expense of a Shuttle servicing mission?"

- *If researchers no longer had access the Space Shuttle or Space Station how would advancement in the material sciences be affected?*

If researchers no longer had access the Space Shuttle or Space Station, then a vital research area in the advancement in the materials sciences would be halted.

With the indulgence of the Committee, I would like to briefly discuss my field of expertise and how orbital research has played a key role in promoting understanding of our physical world. One of the major thematic elements in the research and manufacturing of materials is what is termed the *microstructure.* The understanding and control of microstructure is one of the ultimate goals of both the materials scientist and materials engineer. A material's microstructure includes not only what atoms make up a material (composition), but also *how* are those atoms arranged (structure).What is the geometry of these atomic arrangements and what patterns emerge? Microstructure is a vital theme in materials science because it appears in both major paradigms of material science. That is, the way a material is formed determines its microstructure, and a material's microstructure determines how it behaves. This then, of course, determines whether or not a material is useful for a given engineering purpose.

Historically, during the emergence and development of materials science, scientists were most interested in the two microstructures that could be completely described, perfect single crystals and completely disordered glasses. Nonetheless, important aspects of a specimen's properties depend on a range of complex microstructures that exist between these two extremes. They could not be addressed from a general scientific or engineering methodology until the description and behavior of those complex microstructures were better understood. For most materials, this analysis requires the understanding of how solids form from their melts. For metals and alloys, such an analysis further requires an understanding of what we call dendritic solidification.

During the past fourteen years my research activities have concentrated in the examination of microstructure as it concerns dendritic solidification. Dendritic solidification is the transformation of a molten liquid into a complex, tree-like branching crystalline microstructure. Dendrites are known to appear in the freezing of water, molten salts, ceramic materials, organic materials, and most importantly in the solidification of metals and alloys. I have been personally involved in the experimental investigation of the growth of thermal dendrites. With the aid of NASA's orbital facilities and programs we have made substantial progress because the effective reduction in gravitational body forces on orbit enabled us to understand details of the process that we were not able to accomplish otherwise.

The NASA materials science program has also made substantial gains in the understanding of microstructure. Currently, through its flight programs, NASA is the leading governmental agency in promoting and enabling the understanding of microstructure.

With respect to dendritic solidification in particular, despite the recent advances, the following quote from 1999's National Research Council's (NRC's) report on *Condensed Matter and Materials Physics* makes clear there is more to be done. The report states,

> Very significant progress has been made in the last decade in understanding dendritic pattern formation in crystal growth. That progress, however, has yet to have a major impact on efforts to predict and control solidification microstructures in industrially important materials. In part, the difficulty is that there remain some challenging scientific problems to be solved, such as the 'mushy zone.' Another part of the difficulty is that there is relatively little effort in this area in the United States, especially in industrial laboratories.

Work remains to be done both in understanding additional details about dendritic growth, and in bridging the gap between our understanding of an isolated isothermal dendrite and the final, as-cast microstructure of metals and alloys. The "mushy zone" during dendritic solidification processes is the region where solidification is actively occurring, and the material is part liquid and part solid (hence the term "mushy zone"). This zone consists of many dendrites, each growing in a complicated manner, interacting with their neighboring dendrites. The ultimate scientific goal is to understand this process in its entirety. But to reach this goal, it is necessary to first understand how individual dendrites grow, both isolated from and subject to external influences. This is the substance of several NASA funded projects.

The fact that NASA has been funding research on dendrites since the mid 1970's, both in ground and flight programs, and that the research is now so varied and so vibrant, is evidence of the success of NASA physical science in space program. Using the orbital environment to continue this progress in understanding dendrites is vital. If the access to orbit were eliminated, then the most fruitful avenue of advancement on this important topic will be halted. While orbital research is vital, I content that human tended scientific missions are not absolutely necessary to continued progress in our quest to understand more about microstructure.

And while I have mentioned research on dendrites specifically, I am mindful that the research in which I participate is but one of many examples of productive lines of research in materials science. There are many additional examples of important research being done in the fields of Fluids, Combustion, Fundamental Physics, and Biotechnology. Since I cannot speak authoritatively on these fields, I refer the Committee to experts in those scientific fields.

- *What alternatives exist to carry to orbit micro-gravity experiments that could be conducted autonomously if the Space Shuttle or Space Station were not available for whatever reason?*

To the best of my knowledge, at this time, there are no alternatives for autonomous or remote operations of on orbit experiments if the Space Shuttle or Space Station were unavailable. NASA has extensive ground programs that use drop tubes, drop towers, and parabolic airplane flights to provide from 2 to 25 seconds of apparent weightlessness. These are valuable and productive programs in their own right, but they are not a substitute for long duration orbital flight experiments.

I believe that the Office of Biological and Physical Research in Space has begun to discuss an autonomous or remote platform, but no action or commitment to such a program has been made.

- *If none, how much would it cost NASA to provide researchers such an alternative?*

I do not have the necessary expertise to make a specific financial estimate of what a free flying, on orbit, autonomous or remote controlled facility would cost. However, I can detail the tradeoffs between an autonomous/remote facility versus that of continued human enabled facilities. In my view, these trade-offs favor the autonomous/remote facility.

NASA already has the appropriate expertise at the Office of Biological and Physical Research in Space and at the various field centers to design, built, launch, operate, and recover an autonomous/remotely controlled payload platforms. The only new feature would be the newly designed and built space flight hardware for these operations.

If experiments had to be designed for an autonomous/remotely controlled facility, there would be both cost increases and savings. The cost increases would be to design and built autonomous or remotely controlled experiments in place of those that were formerly designed for astronaut operation. Similarly, those experiments that were built to operate autonomously or remotely could be scaled back some because of the relaxation of constraints necessary for flight aboard a human tended spacecraft.

The greater cost savings would occur because there would be no need to launch and operate Shuttles dedicated to physical science experiments. There would be significantly less upmass to the International Space Station for physical science experiments. The Space Station itself could be scaled back as there would be no need for laboratory space dedicated to physical science experiments, and there would be no requirements for astronauts to be trained or travel to orbit to conduct these physical science experiments.

In addition, there would be some secondary cost savings as well. Currently, payload experiments are designed and built to exacting standards so as to certify that a given experiment has a greater than 90 percent chance of success. This high standard is necessary since the cost and risk of bringing that payload to orbit is so high. If a new unmanned autonomous or remote facility could be brought online and made operational at a lower cost per launch, the probability of success standards could be relaxed to, say, 75 percent, with a much greater percentage reduction is design, construction, testing, certification, and operating costs. This is so because if a given experiment were not successful, it could be modified and re-launched on a future flight quickly and inexpensively. In other words, a whole new design and operating philosophy would occur with significant cost savings.

Lastly, with an autonomous or remote facility as described above, it would be significantly easier and more likely to maintain launch and operating schedules. The reliability of scheduling would also result in a cost savings and would give the program a consistency that would benefit all current investigators and help attract graduate students and post doctoral associates into the program.

- *To what extent, if any, would a more ambitious mission for NASA, such as sending people back to the Moon or to Mars, be likely to provide materials science researchers with unique opportunities for experimentation?*

It is very unlikely that a more ambitious mission for NASA, such as sending people back to the Moon or to Mars, would be likely to provide materials science researchers with unique opportunities for experimentation. Materials science is a laboratory science aimed at understanding and controlling the inner workings of materials. Unlike like observational sciences and planetary geology, the Moon and Mars have little or nothing to offer to the physical laboratory sciences.

The key element of the on orbit free fall environment for materials science researchers is the effective elimination, or great reduction, in gravitational body forces. This reduction effectively eliminates the hydrostatic pressure in fluids, and thereby effectively eliminates buoyancy, sedimentation, and natural convection while giving greater reign to other convective processes and surface effects. This allows a materials scientist to try to understand fundamental phenomena in how materials are formed and function in a way that is simply not possible on an Earth based, or other planetary, laboratory.

Naturally, if NASA had a more ambitious mission, such as sending people back to the Moon or to Mars, materials science would be one of the enabling technologies, much like the present NASA sponsorship in materials for radiation shielding. The need for such enabling technologies would benefit materials science as there would be increased funding for certain lines of research. However that research work would be the more traditional Earth-based laboratory materials research and is not really different than that which is taking place in academic, national, and industrial laboratories today.

Additional Comments Related to the Specific Questions Submitted by the Chair

In addition to my statement directly addressing the specific questions posed by the Chair, I have a number of comments that indirectly address those questions.

Several of the questions addresses to me were specifically directed to my professional experience in condensed matter and materials physics. I answered these questions to the best of my ability. In addition, when I believed my knowledge to be up to the task, I inserted comments about other of the disciplines under the auspices of the Office of Biological and Physical Research in Space.

When colleagues heard that I was testifying here today, one said something like "Don't say anything bad about Fundamental Physics." Well I won't. But I would like to do one better. I affirm the tremendous value of the research in combustion, fluids, fundamental physics, and materials science that has been done by brilliant and talented scientists, and it remains my fervent hope that this fundamental research will continue to take place on orbit. I cannot make, and will not attempt to make any value judgment that places one of these disciplines, even my own, above another.

I say this for the real fraternity I belong to is science, and when one science is diminished in competition with another, all are diminished. It is crucial that all sciences have a path to the future. A while back when the crisis in science funding occurred in the Office of Biological or Physical Research, a fellow materials scientist advised me to get out there and lobby for materials the way other scientists are doing for their discipline. To the extent that this was true, it was deleterious to all the so named "microgravity" sciences, and other sciences as well. I will not engage in that. Despite any criticisms I have expressed, I am a committed advocate of the on-orbit environment as one of many vital national resources for scientific advancement across the disciplinary boundaries.

Lest my advocacy for an autonomously or remotely operated facility for the physical laboratory sciences in low-Earth orbit be misinterpreted, I also favor a continued human presence in space. We may always need astronauts to assume certain risks human exploration and development of space. I agree with NASA when they say that "exploration is what great nations do" and "exploration is part of the human fabric." Space shuttles and space stations may indeed be necessary to fulfill that need to explore. I am only advocating that a better balance be found for autonomous, remote and human enabled programs. I fully support NASA and the country in looking for a grand overarching mission, including that of the future of human space flight. However, the time has come to decouple the human exploration and development of space from the needs and benefits of conducting basic research in the laboratory physical sciences in low-Earth orbit.

I think that many scientists fear that if this decoupling takes place, that the basic laboratory physical sciences would disappear from NASA's portfolio in favor of the more dramatic and compelling future of human space flight. I share that fear, and if that came to pass it would be a great shame. However, the cost of using astronauts to perform science experiments to gain public support of science in space is not justified. All the orbital experiments that can be conducted autonomously or remotely should be done in that mode. The Office of Biological and Physical Research portfolio is a vibrant and vital program. I truly believe that moving the physical science research program, and as much of the biological research program as possible, to a fully autonomous or remote facility would benefit both the program itself and be a great complement to NASA's larger mission.

Conclusion

As stated earlier, NASA already has the appropriate expertise at the Office of Biological and Physical Research in Space and at the various field centers to design, built, launch, operate, and recover an autonomous/remote controlled payload platform. I believe, based on the way NASA has created and cultivated such a robust, professional and productive laboratory science program on orbit, that they could assuredly manage a tremendously productive autonomous/remote facility as a vital national resource, and do so at a reasonable and reduced cost and at greatly reduced risk.

Again, thank you for the opportunity to address you here today.

Exhibit 1

June 29, 2003, Sunday
EDITORIAL DESK

How Science Brought Down the Shuttle

BY MATTHEW B. KOSS (OP-ED) 954 WORDS

WORCESTER, Mass.—As a scientist whose experiments were carried out on three missions of the Space Shuttle *Columbia,* I have been following with great interest the findings of the board looking into the Shuttle's demise. Though a piece of foam may be found ultimately responsible, as the *Columbia* Accident Investigation Board announced last week, on some level I feel personally culpable for the loss of the seven astronauts. In-orbit experiments like mine have been used to justify manned space projects like the Shuttle for decades.

The truth is that the vast majority of scientific experiments conducted in orbit—including my own—do not require astronauts. The main reason for in-orbit experimentation is to observe how a scientific process works without gravity-driven influences. But almost all of these tests, save those that must be done on humans, can be controlled from the ground via computer or by robots in space. In fact, some of the best work is done this way when the crew is asleep, not moving about and causing vibrations.

To be sure, a lot of important science has been conducted in orbit. For example, research on the large single crystals of silicon that are at the heart of computer chips arose from the many detailed studies of crystal growth on the Space Shuttle. But, in fact, experiments like these are often more efficient and yield more fruitful results when done without the involvement of astronauts.

The science performed on the Shuttle can be classified as either a payload or a mid-deck laboratory experiment. Payload experiments are self-contained packages mounted in the payload bay, the wide open space in the back of the Shuttle. They either run autonomously or are controlled remotely via computers on the ground. Laboratory experiments are performed in the mid-deck or Spacelab module, and are done by the astronauts with computer assistance from the ground.

My experiments, on the fundamentals of how liquids turn into solids, were originally planned for the mid-deck, where they would be controlled by an astronaut who was scheduled to do eight tests. But because of launching delays, the project was changed to a payload experiment that would perform tests autonomously. During the flight, initial data was transmitted to the ground and analyzed by me and my colleagues. Performing the experiment remotely, without crew involvement, allowed us to do 63 test runs.

Remote-controlled experiments may seem to contradict images we have grown accustomed to—of happy, busy astronauts manipulating scientific equipment or talking about the science on board, or occasionally reporting on the objectives of experiments. But this public image of astronauts as laboratory scientists working on their own experiments is a bit misleading. Since the Mercury 7 pioneers, the astronaut corps has served one overriding political and public relations purpose—to sell the space program.

The idea of using the Space Shuttle as a scientific laboratory actually came about after the Shuttle's design was already in place. The Shuttle program was conceived in the waning days of the *Apollo* program as the best option to continue a manned space program at the lowest cost. However, without a place to shuttle to, and not nearly enough satellites that needed a Shuttle to launch or repair them, the Shuttle program succeeded in doing little beyond creating a human presence in space. The idea of the Shuttle as an in-orbit lab was used as a justification for investment in its future.

Similarly, the International Space Station has been aggressively marketed as a science lab. In fact, the Station is seriously flawed in that too much crew time needs to be committed to Station maintenance, and too many of the planned experiments depend on crew operations when they could more effectively be done without them. In many cases, the crew is needed only to deploy an autonomous experiment.

Because of cost overruns and budget problems, the Station's crew was cut back to three from the planned seven. Originally, 120 astronaut-hours per week were to have been devoted to science; this has been cut back to 20 hours per week. With the Shuttle program grounded once again, it has become even more difficult to exchange crews, replace experiments or repair and refurbish equipment.

Scientific experimentation in space can be safer and more cost effective using long-duration remote controlled orbital spacecraft. At the outset, the costs of developing this technology may appear greater than simply perfecting the Shuttle. But if you do not need to provide a safe and sustaining environment for astronauts—making sure takeoffs and landings aren't too fast, providing enough food and oxygen—the overall cost will be significantly reduced.

If NASA is not able to convince the public of the importance of science in orbit without astronaut involvement, then so be it. At least America's refusal to support science would be honest, would not needlessly endanger human lives or compromise the integrity of science and scientists.

We will always need astronauts to assume certain risks to develop the technology that allows for human exploration of space. The space shuttles and space stations may be necessary to fulfill that mission. However, we need to separate the goal of scientific experimentation from the desire for space exploration. I hope that the unfortunate death of the *Columbia* astronauts will forever sever the false link that has been created between the two.

Astronauts do not risk their lives to perform scientific experiments in space. They fly to fulfill a much more basic and human desire—to experience the vastness of space.

BIOGRAPHY FOR MATTHEW B. KOSS

Matthew B. Koss is an Assistant Professor of Physics at the College of the Holy Cross in Worcester, Massachusetts (2000–present). He earned an AB degree from Vassar College (1983), and a Ph.D. in Experimental Condensed Matter Physics from Tufts University (1989). Following his graduate work, he was a research scientist and research professor in the Materials Science and Engineering Department at Rensselaer Polytechnic Institute (1990–2000).

Currently, Dr. Koss is a the Co-Investigator of "Materials Science as an Avenue for Interdisciplinary SMET Education," and "The Study of Dynamics and Tip Selection in Thermal Dendrites via Pressure Moderated Step Changes in Supercooling." In addition, Dr. Koss was the Lead Scientist for the "Isothermal Dendritic Growth Experiment," a basic research project on dendritic solidification that conducted successful Space Shuttle flight experiments on STS–62, –75, and –87 in 1994, 1996, and 1997, respectively. He was also the Co-Investigator of the "Rensselaer Isothermal Dendritic Growth Experiment" (1999–2003), a continuation of his work at Rensselaer, and the Principal Investigator of the "Transient Dendritic Solidification Experiment" (1997–2003), a flight definition experiment that was being developed for operation on the International Space Station and that was "returned to ground status" in 2002.

Dr. Koss is a member of the American Institute of Aeronautics and Astronautics (AIAA), the American Association of Physics Teachers (AAPT), the American Physical Society (APS), and Sigma Xi—the Scientific Research Society. Currently, he serves on the AIAA Technical Committee on Microgravity and Space Processes, is a Councilor-at-large for the New England Section of the AIAA, and is the Holy Cross Affiliate Representative of the Massachusetts Space Grant Consortium (MASGC). Dr. Koss has authored or co-authored over 50 technical papers and has prepared or presented over 100 technical talks and presentations. He also served as an AIAA Distinguished Lecturer from 1999–2002.

In addition to his research and professional activities, Dr. Koss is involved in outreach and education. He developed and organized a two-week workshop to introduce K–12 teachers to the sciences related to apparent microgravity. He continues to work to develop programs and materials for teachers, their students, and the community to learn about science, engineering, and NASA's Physical Science in Space Program.

A lifelong Red Sox fan, Matthew, his wife Betsy, and his daughter Frederica reside in Shrewsbury, Massachusetts, approximately a one-hour drive to Fenway Park.

Chairman BOEHLERT. Thank you very much, Dr. Koss.

Dr. Roland.

STATEMENT OF DR. ALEX ROLAND, PROFESSOR OF HISTORY, DUKE UNIVERSITY

Dr. ROLAND. Thank you, Mr. Chairman.

The United States may have a long-term future in human space flight. For the near-term, however, human space flight should be suspended, in my opinion, or at least drastically curtailed. If the Shuttle flies at all, it should fly unmanned or at worst with a minimal crew. The Space Station should be mothballed or converted to a space platform, a research facility to be visited periodically for refueling, maintenance, and changing experiments. The upcoming mission to refurbish the space telescope should be canceled or flown only by the astronauts actually conducting the repairs. For the foreseeable future, all orbiting scientific instruments should be designed to function unattended and be launched on expendable launch vehicles to the optimal orbits.

The problem, of course, is the Shuttle. Humans may one day fly to Mars and beyond, but it won't be on the Shuttle. While the Shuttle is a technological marvel, it is also the world's most expensive, least robust, and most deadly launch vehicles. On average, one astronaut dies for every eight flights. I don't know of any transportation system, not even an experimental system, approved to operate with such a record. After the *Challenger* disaster, the Rogers Commission and every other body that studied the accident gave NASA the same advice. First, do not rely on the Shuttle as the mainstay of the space program; it is too expensive and too fragile to ever fill that role. Second, begin at once to develop a replacement vehicle. Sixteen years later, the *Columbia* disaster found NASA massively dependent on the Shuttle with no replacement vehicle in sight. The Shuttle has never been, and never will be, the launch vehicle that NASA wants it to be, yet the agency appears determined to return to business as usual.

At least for the short-term, we do not need the Shuttle and we do not need people in space. Anything we want to do in space we can do more cheaply, more effectively, and more safely with automated spacecraft monitored and controlled from Earth. The reason is simple. Whenever people are put on a spacecraft, its mission changes. Instead of exploration or science or communication or weather, the mission of the spacecraft becomes life support and returning the crew alive. This limits where the spacecraft can go, how much equipment it can carry, how long it can stay, what risks it can take in pursuit of its mission. The net impact of people on a spacecraft is to greatly limit its range and capabilities without adding any value that can begin to compensate for these drawbacks. A rough rule of thumb, first introduced by NASA Associate Administrator George Low in the *Apollo* program, is that putting people on a spacecraft multiplies tenfold the cost of the undertaking.

For more than 40 years, NASA has been sending humans and machines into space. It has spent about $\frac{2}{3}$ of its funds on human space flight, about $\frac{1}{3}$ on automated spacecraft. The most important returns, after *Apollo,* have come from the machines: the space probes, the scientific satellites, the communications, geodesy, weather satellites. The return on manned space flight has been mostly psychological, a kind of public entertainment based on flying the astronauts as an end in itself. NASA used to call this "the next logical step," envisioning a succession of manned projects culminating in a human mission to Mars. Now NASA simply says that it has achieved a "permanent human presence in space." It has not made clear what the people are to do there other than to take their own pulse in an endless round of experiments to understand the physiological risks of flying to Mars and back.

Before we can fly to Mars, we must first master flight to low-Earth orbit. Indeed, if we were to commit tomorrow to a human mission to Mars, it would still cost more to get to low-Earth orbit than it would to get all of the rest of the way to Mars and back. This is the real obstacle to our future in space. It is the obstacle the Shuttle was supposed to overcome. After 30 years and tens of billions of dollars, it is clear that the Shuttle will never be the vehicle NASA promised. We must recognize that reality, scrap or severely curtail Shuttle operations, and get on with the challenging but promising business of building the launch vehicle or vehicles we need.

Thank you, Mr. Chairman.

[The prepared statement of Dr. Roland follows:]

PREPARED STATEMENT OF ALEX ROLAND

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At least for the short-term, we do not need the Shuttle and we do not need people in space. Anything we want to do in space, we can do more cheaply, more effectively, and more safely with automated spacecraft monitored and controlled from Earth. The reason is simple. Whenever people are put on a spacecraft, its mission changes. Instead of exploration or science or communication or weather, the mission of the spacecraft becomes life support and returning the crew alive. This limits where the spacecraft can go, how much equipment it can carry, how long it can stay, and what risks it can take in pursuit of its mission. The net impact of people on a spacecraft is to greatly limit its range and capabilities without adding any value that can begin to compensate for these drawbacks. A rough rule of thumb, first introduced by NASA Associate Administrator George Low in the *Apollo* program, is that putting people on a spacecraft multiplies tenfold the cost of the undertaking.

For more than forty years, NASA has been sending humans and machines into space. It has spent about two-thirds of its funds on human space flight, about one-third on automated spacecraft. The most important returns, after *Apollo*, have come from the machines—the space probes, the scientific satellites, the communications, geodesy, and weather satellites. The return on manned space flight has been mostly psychological, a kind of public entertainment based on flying the astronauts as an end in itself. NASA used to call this "the next logical step," envisioning a succession of manned projects culminating in a human mission to Mars. Now NASA simply says that it has achieved a "permanent human presence in space." It has not made clear what the people are to do there, other than take their own pulse in an endless round of experiments to understand the physiological risks of flying to Mars and back.

Before we can fly to Mars, we must first master flight to low-Earth orbit (LEO). Indeed, if we were to commit tomorrow to a human mission to Mars, it would still cost more to get to LEO than it would to get at all the rest of the way to Mars and back. This is the real obstacle to our future in space. It is the obstacle that the Shuttle was supposed to overcome. After thirty years and tens of billions of dollars, it is clear that the Shuttle will never be the vehicle NASA promised. We must recognize that reality, scrap or severely curtail Shuttle operations, and get on with the challenging but promising business of building the launch vehicle or vehicles we need.

This can be done with no increase in NASA's budget. The money saved by stopping or limiting Shuttle operations and by moth-balling or converting the Space Station will free up enough funds annually to do what the Rogers Commission told NASA to do seventeen years ago. Of course, additional funding might accelerate the process, but this is not a race, like *Apollo* was. It is a simple, straight-forward research and development program committed to the long-term development of our access to space. It may take five to ten years to develop a space plane to shuttle astronauts to LEO. It will probably take ten to twenty years to develop a vehicle that will provide truly reliable and economical launch to LEO. There is no reason to believe that the public will lose interest in space if there are no astronauts in orbit. Manned space flight shut down through much of the 1970s while we developed the

Shuttle. Neither Congress nor the public abandoned NASA or the space program in that time. Indeed, a serious research and development program might actually increase public interest. The Shuttle now captures public attention only when it flies celebrities or fails catastrophically.

Another way to restore public interest in the space program during a sustained period of launch vehicle development is to divert some of the savings from Shuttle and Space Station operations to unmanned space flight. The international fleet of automated spacecraft currently on its way to Mars holds out far more promise of exciting discovery than does one more astronaut running a treadmill in LEO. Space science has been repeatedly taxed over the years to staunch the budget hemorrhaging in the Shuttle program. Many worthy projects await funding.

BIOGRAPHY FOR ALEX ROLAND

Alex Roland is Professor of History at Duke University, where he teaches Military History and the History of Technology. A 1966 graduate of the Naval Academy, Professor Roland served in the Marine Corps before taking his Ph.D. in History at Duke in 1974. From 1973 to 1981 he was a historian with the National Aeronautics and Space Administration. Since returning to Duke in 1981, he has chaired the Department of History (1995–2000) and held the Harold K. Johnson Chair of Military History at the Military History Institute, U.S. Army War College, and the Dr. Leo Shifrin Chair of Naval-Military History at the U.S. Naval Academy. His books include *Underwater Warfare in the Age of Sail* (1978), *Model Research: The National Advisory Committee for Aeronautics* (1985), *The Military Industrial Complex* (2001), with Richard Preston and Sidney Wise, *Men in Arms: A History of Warfare and Its Interrelationships with Western Society* (5th ed., 1991), and with Philip Shiman, *Strategic Computing: DARPA and the Quest for Machine Intelligence,* 1983–1993 (2002). He has edited *A Spacefaring People* (1985) and, with Peter Galison, *Atmospheric Flight in the Twentieth Century* (2000). He is a past President of the Society for the History of Technology and the Vice President of the Society for Military History.

Chairman BOEHLERT. Thank you very much.

Dr. Murray.

STATEMENT OF DR. BRUCE MURRAY, PROFESSOR OF PLANETARY SCIENCE AND GEOLOGY EMERITUS, CALIFORNIA INSTITUTE OF TECHNOLOGY

Dr. MURRAY. Thank you, Mr. Chairman and Members of this committee. I am very, very pleased that you are undertaking these hearings, because indeed the problem is one of vision, as I noticed this committee really has permanently imprinted on its walls behind you, and from that a willingness to really look what that means. And so I am coming from that point of view.

I have been involved in space exploration for 40 years, mostly with the automated systems, but I have been a strong advocate of human space exploration of Mars. That has been hard to do at NASA, and so I personally have used the planetary society of private and non-profit advocacy as a platform.

The reason it has been so hard to do with NASA, and this goes back to 1983 or '84, was you will always get the statement from them, "We will think about that after Space Station is completed." NASA has had that as—it has been focused on that. Of course, the Shuttle is part of that. And the consequence, as everyone seems to agree, the U.S. is bogged down in low-Earth orbit.

What is needed here is not so much technology. I don't think it is primarily a financial problem. It is a perspective problem on ourselves. It takes a realistic assessment of program alternatives and it takes a lot of political courage.

Latter is the part that you can both contribute to directly and certainly contribute to indirectly by building public and governmental consensus about what to do. I believe that the way out of this is that—being bogged down to Earth orbit—and unless we really embrace a long-term destination for humans in space, there is no point in the long run of doing what we are doing now. It is that simple. We are bogged down, not just technically, but we are bogged down in terms of purposes. It is tragic when people die in that purpose. It is not tragic, it is sad when people die, say, in a military conflict of great importance, but it is very sad when they die doing something that isn't really worth doing with humans. The only thing that really advances is the idea that we are advancing as a country and, in that sense, the world in a broader sense out on an important destination which is to determine whether or not, in this case, Mars, which is the only potentially inhabitable place outside of Earth, if Mars is a potential habitat for human activities in the future. That is the dream. It may not be true. We don't know.

We can tell a lot by robots, and we are learning many good things. For example, the recent Odyssey results revealing the presence of waterways over a much broader parts of the planet is really important. But we won't know whether we can make that a place to begin for human activities until humans go and try to do it. That should be their objective. It should not be to go demonstrate technology, go place the American flag there or whatever. That is the *Apollo* thinking from a different era. It was very successful then, but it was that kind of thinking which made the 1989 attempt, the only other attempt to do something like this, such a disaster politically and every other way because it wasn't the right reason.

So we have to embrace the right reason. We have to embrace the fact that this is something that is going to take a while and not going to get it done in two presidential cycles or however many congressional ones. So that means that the program itself has to be composed of a lot of short-term milestones and efforts, each of which is enabling to the longer goal, each of which is affordable, and each of which is interesting and popular. That is the key to this dilemma. That is how we get out of it.

In order for that to happen, NASA is going to have to feel pressure to produce an alternative to their current Space Station and Shuttle plan. It is clear they are as committed to that as they had been. They don't see a way out of it, and so they are going to sit there and try as best as possible to stay on that track. Now if they are successful, it means that human space flight will probably disappear either gradually by a loss of interest or by catastrophically when the next fatality has occurred either on the Shuttle or on the Station itself.

We are that close. It would be terrible, and it is horrible legacy of this generation, of this political leadership of which you are a part, that we could lose this wonderful thing we started with, especially *Apollo*. We could lose it because we didn't have the political courage to recognize that we have gotten ourselves in an insupportable situation.

I have written testimony, and I am looking forward to answering detailed questions on how to do all of this, but I will leave you with both thanks for having a chance to talk to you and saying that fundamentally the problem is your problem. It is a political leadership problem, a perceptual problem. It is not a financial problem. It is not a technical problem.

Thank you very much, Mr. Chairman.

[The prepared statement of Dr. Murray follows:]

PREPARED STATEMENT OF BRUCE MURRAY

"EMBRACING THE PROMISE OF SPACE"

Mr. Chairman and Members of the Committee:

It is most important now that this committee is helping to develop consensus about where America's human space flight program should be headed. I am grateful for the opportunity to express my personal views today on that subject.

A remarkably enduring American belief in the promise of space has sustained NASA human flight through seven Presidencies and twenty-one Congresses, through the grand accomplishment of the *Apollo* human landings on the Moon, followed by our return to more prosaic activities in low-Earth orbit, through the end of the Cold War and of U.S.-Soviet nuclear-armed rivalry, through the powerful post-Cold War trends of divestiture of governmental functions, through the Internet Revolution, and through the striking domestic cultural and attitudinal changes accompanying such tumultuous events.

However, four decades and 241 human flights placing 429 individuals in space have also demonstrated that this popular endeavor is intrinsically risky and expensive. Fourteen U.S. astronauts and four Soviet cosmonauts have died in space. In addition, three others died in the *Apollo 1* fire during essential tests on the launch pad in January, 1967. Human space flight has always been the major NASA priority, consuming today about seven billion dollars, one-half of NASA's total funds and a not insignificant component of the discretionary portion of the federal budget.

Now, as this hearing illustrates, many are questioning the wisdom of human flight itself in the wake of the *Columbia* disaster and of the CAIB Report: "Why spend all those federal tax dollars year after year on just sending astronauts in orbit when we have so many other needs here on Earth?" "Where are we going in space, anyway?"

Why Human Space Exploration?

Indeed, the fundamental problem is that we truly have no compelling destination in space for Americans. Since the 1970s, NASA thinking has been dominated by the internal dogma that the space station IS the destination. It was originally targeted to begin initial operations in the early 1990s. Instead, an ISS of limited capability is still years away and likely to do very little to advance human exploration of space. Furthermore, its promised benefits to commercial manufacturing and to medical research were eclipsed long ago by new technology and new manufacturing processes here on the ground. Most seriously for America now, it doesn't open the way to affordable future human flights beyond Earth orbit. Rather than beckoning as an orbital portal to expanding opportunities, space station is looking more and more like a costly orbital dead end.

There is a growing sense we have lost our way in space and are bogged down in low-Earth orbit, driven by past domestic and political commitments rather than by genuine enthusiasm and excitement for the future. At this critical juncture we must once again infuse our human space flight program with a sense of exploration and adventure. We must once again commit ourselves to human space *exploration.*

Humans have been pushing beyond familiar locales throughout history for a variety of reasons including survival, curiosity, power, idealism, and economics. The Soviet Union initiated space exploration for domestic and international prestige with Sputnik in 1957 and with Gagarin in 1961, quickly followed for the same reasons by the U.S. with Explorer 1 and Glenn. (This pattern currently is being repeated by China four decades later). The U.S. then raised the stakes in 1961 by initiating the *Apollo* project to the Moon as a Cold War priority presidential initiative. President Kennedy succeeded in focusing large resources to challenge the Soviet Union to a space race only we could win. The project objective was simple and clear—get an American to the surface of the Moon and back alive by the end of 1960s. Thus NASA was given a dramatic and popular human mission of exploration with the highest national priority and a fixed time scale.

To its lasting credit NASA won that race to the Moon, dramatically demonstrating American technological superiority to the world and to our Soviet adversaries. Most significantly in retrospect is that *Apollo* expanded forever all humanity's sense of its own potential. We must similarly challenge our current visions for future human space endeavors.

However, that *Apollo* success also removed the overriding national security need which had powered NASA through the 60s and early 70s. As a consequence, NASA was led to abandon further human space exploration as politically unsupportable and set off, unsuccessfully it turns out, to try to create a sustainable utilitarian role for humans in Earth orbit.

Where Should We Be Heading Beyond Earth Orbit?

So what should be our destination beyond Earth? Where is that place worth the inevitable risk to human life involved, and is compelling enough to attract sustained public support over decades?

Because NASA's only experience with human travel beyond Earth orbit ended in 1972, NASA in 1989 was not well prepared when a president actually did ask for a plan to go back to the Moon and on to Mars. NASA's backward-looking approach concerning the rational for and implementation of future human flights to Mars was to cast it in the *Apollo* mode—as a demonstration of U.S. capability to get humans to Mars and back successfully on a politically realistic time scale, initiated by a high profile presidential initiative involving a significant increase in NASA expenditures. But, there wasn't then nor is there now any overriding national security need for a crash program to send Americans to Mars or Moon or anywhere else in space. Hence a costly political embarrassment resulted in 1989, leading subsequent administrations to be antagonistic toward any NASA efforts to develop and promote a more thoughtful understanding of the "how, when and why" of human travel beyond Earth orbit.

Why then should America commit now to send humans to Mars in the future? The Moon and Near-Earth asteroids are plausible targets for new human scientific expeditions during the 21st Century. Privately funded "adventure tourism" probably will spread from the Mt. Everest to Earth orbit and eventually to the Moon. Astronauts may play an important role in installing crucial equipment on distant space observatories as they did on Hubble. But, *only Mars offers a plausible habitat for humanity beyond Earth.* Only Mars offers Earthlings another potential venue, richly endowed with the essentials for life easily accessible from its surface. Carbon, Nitrogen, and Oxygen are abundant in its atmosphere. The U.S. Mars Odyssey spacecraft recently discovered a far greater distribution of accessible ice than had ever been imagined previously. Space suits and sealed domes will still be required for humans on the surface, to be sure, but greenhouses using local resources are entirely feasible, as is production of liquid water and breathable oxygen for human use from the surface ice. Liquefied hydrogen and oxygen for transportation and portable energy sources are likewise feasible, especially as small nuclear power systems become available to supplement indigenous solar energy in coming decades.

Mars has as much land area as does Earth. Mars is the true space frontier, the legitimate abode for the dreams of the young for many generations to come. America should lead the world in that grand, positive human endeavor, using some of our enormous and visible technological capability to dramatically demonstrate our enduring commitment to Earth's future beyond the blood and conflict which inevitably will make up much of the 21st Century.

How to Make Humans Going to Mars Affordable and Popular

Firstly, American objectives for the first human expeditions to Mars must evolve beyond Apollo-like demonstrations of national technical capability, as in 1989, to leadership of a long-term international human space endeavor to determine directly Mars' habitability.

The international program of Antarctic exploration initiated in 1957 affords a powerful historical model of a highly successful long-term scientific exploration with unquestioned benefit to all inhabitants of planet Earth, often in ways not foreseen initially. Likewise, the multi-national relationships and experiences of the International Space Station provide contemporary experience with the benefits and challenges of real collaboration on complex human space systems. The legacies of both Antarctic and ISS inevitably will influence international attitudes about going to Mars with humans eventually, and must be elucidated and fused.

So far, almost all open discourse and study of multi-national Mars human exploration has been non-governmental. NASA must now help lead an open process involving all space-faring nations as well as the public and private sectors in which these various experiences and viewpoints can be gradually fused into some consensus on overall objectives, as well as identification of various approaches to how and when such a journey might be carried out.

Secondly, NASA must lead a broad and open look at alternative technical approaches to human flight to Mars, recognizing that Apollo-like commitments to huge and expensive new launch vehicles are unrealistic. The timescale for the first human missions to Mars should be flexible, as should be the relationship to ISS operations and any Shuttle replacement programs. Alternatives to previously-publicized NASA thinking need to be included such as 1) Orbital assembly, fueling and launch, 2) Synthesis of likely human landing requirements with current robotic science missions and planning to provide for "Mars Outposts" and associated infrastructure to support eventual human missions which would be emplaced by nearer-term automated launch vehicles, 3) Maximum use of advanced information technology, including tele-operated and autonomous systems, 4) Conceptual design of true deep space human spacecraft characterized by greater overall reliability than previous Earth orbital and *Apollo* space craft that never had to operate more than a few days from emergency return. Similarly, human deep space travel must incorporate a far greater degree of regenerative systems than previously, and finally 5) Plans for candidate earlier human flights for further scientific exploration of the Moon or of a Near-Earth Asteroid, or to future space observatory sites should conceived and organized so as to provide maximum benefit to the eventual Mars endeavor.

Thirdly, NASA must develop an overall schedule for the Human exploration of Mars that 1) is comprised of a series of frequent affordable steps and milestones, 2) is not characterized by a significant early funding requirement, and 3) acknowledges the consensus of mission objectives and alternative technical approaches resulting from the first two items above.

Fourthly, and most important, the political leadership of this country must also insist on NASA developing and presenting a range of realistic alternatives to its current Shuttle/Space Station plans that can enable a credible national commitment to a paced Mars human flight program. These alternatives necessarily should include multi-year suspensions of U.S. human flight as NASA elected to do in 1975–1981, when NASA suspended U.S. human flight entirely after the Apollo-Soyuz mission until the first Shuttle test flight in order to create the budget wedge enabling the Shuttle to be developed. Only by considering such painful alternatives can the relentless decline into mediocrity and irrelevance of U.S. human space flight be reversed within realistic budget considerations. There is no "Business as Usual" pathway for the U.S. into the future. The problems of being bogged down in Earth orbit will get worse. . .the choices even more painful. . .until U.S. human flight likely will simply disappear.

Renewing Humanity's Hope in Space

A commitment to lead the international human exploration of Mars can afford the American people and the world a powerful sense of a hopeful, promising future in space. The near-term challenges are not budgetary, but conceptual and attitudinal. It is time to show everyone that we are not bogged down in space—or on Earth—by embracing that most exciting, but feasible, vision of our future in space.

This will take realistic programmatic thinking and political courage.

BIOGRAPHY FOR BRUCE MURRAY

Dr. Murray, 71, is Professor Emeritus of Planetary Science and Geology at the California Institute of Technology in Pasadena, California. He has been at Caltech since 1960 and currently teaches courses in Planetary Surfaces and supervises graduate and undergraduate student research on Mars.

He was Director of the NASA/Caltech Jet Propulsion Laboratory from 1976 to 1982. Major projects under his term included the Viking landings on Mars and the Voyager mission through Jupiter and Saturn encounters. In 1979, he and Carl Sagan and Louis Friedman founded The Planetary Society, a 70,000 member international organization dedicated to exploring the Solar System and to the search for extra-terrestrial intelligence (SETI). He continues as Chairman of the Board of Directors.

Dr. Murray was a member of the Mars Television Teams on Mariner 4 (1965), Mariners 6 and 7 (1969), and Mariner 9 (1971–72). He was the Television Team leader for the Mariner 10 flyby of Venus and Mercury (1973–75). He was a member of the scientific teams of the Russian Phobos '88 Mission, and the unsuccessful Mars '96 Mission. He is a Participating Scientist on the U.S. Mars Global Surveyor mission (1997–present). He also was a Participating Scientist on the Mars Polar Lander and Mars Climate Orbiter missions which failed in late 1999 and also on the Mars Microprobe (DS–2) which likewise failed in December 1999. He served as a Consultant to the Mars Program Independent Assessment Team ("The Young Committee") which investigated those Mars failures of 1999. He previously served on various government advisory committees including the PSAC Science and Technology Panel (1967–72), and the NASA Advisory Committee (1995–99) and was a Consultant to the Space Council (1990–92). His memoir *"Journey into Space"* (Norton, 1989) reflects this long involvement with space exploration.

Dr. Murray also has a long-standing interest in structured ways to analyze and visualize potential future outcomes of alternative societal and natural circumstances, beginning with his book *"Navigating The Future"* (Harper Row, 1975). He was a consultant to the *"2050 Project,"* a collaboration between WRI, The Brookings Institution, and the Santa Fe Institute from 1991–95. From 1993 to 1999 he worked with the John and Mary Markle Foundation to determine how new information technology may be developed to facilitate deliberative discourse on critical issues. Currently, he is Co-Producer of the PBS Series "Closer to Truth" and of the accompanying website at http://www.pbs.orc/closertotruth/.

Dr. Murray has published over 130 scientific papers and authored or co-authored six books. He received his college education at M.I.T., culminating in the Ph.D. in 1955. His full publication list and CV are available at http://www.gps.caltech.edu/~bcm/HomePage/.

DISCUSSION

VISION

Chairman BOEHLERT. Thank you, Dr. Murray.

Everyone talks about vision. I translate that to mean a grand strategy, but the vision or the grand strategy doesn't mean anything if it isn't a shared vision. Right now, it is a blurred vision and we have got to bring it into sharper focus. And one of the things that I was taken by in the Gehman report and it said rather specifically that the budget didn't match NASA's priorities. Well, in that instance, it seems to me that NASA has to face the reality and rethink its priorities to address that. That hasn't happened.

The research part is our part on this committee. You know, we can give out the grand strategy, the grand vision, and we can authorize money and virtually unlimited dollar amounts, but what good is that if it is not supported by budget requests from the Administration or it isn't supported by the actual dollars from the Appropriations Committee. So we are all talking about the same thing. We have got to all get on the same wavelength, and I am afraid we are not there yet, and we have got a lot of work cut out for us.

PRIORITIES

Here is a general question for all of the witnesses. In '90, the Augustine Commission laid out a set of priorities if NASA's budget was flat. Those priorities were space science, one, two, Earth science, we used to call it "Mission to planet Earth," three, technology development, four, development of a heavy lift launch vehicle, and five, space exploration, we used to call it "Mission from planet Earth." Do you agree with those priorities? If not, can you give us a new set of priorities and what level of funding would NASA need to begin to implement the vision?

Dr. Griffin, I will start with you. That is a tall order.

Dr. GRIFFIN. Thank you, sir.

Now I agree with the ultimate priority for useful things to do. I would not have them in that order, as I think is probably pretty clear from my earlier remarks. I——

Chairman BOEHLERT. Would you care to share your order?

Dr. GRIFFIN. My order would be the chronological order in which I would do them. Certainly, it would be starting to develop a heavy lift launch capability, because without that there is no human exploration program, which I would then place second. I would place space science third, Earth science fourth, and possibly surprisingly, technology fifth. I don't really mean technology is the fifth most important thing. What I intend to imply is that technology advancement—and accomplishments, I think is wasted money. And so when one undertakes the—reach certain destinations or achieve certain goals, whatever, whether they be in space science, Earth science, or whatever, reaching those goals entails, usually, doing things we don't currently know how to do. And then we implement the technology programs necessary to get there. But developing technology absent specific goals, to me, is wasteful.

Chairman BOEHLERT. In your testimony, you state specifically you need to see an allocation of about $20 billion per year, and then you go on to list what you hope to achieve with that $20 billion. And the list is pretty extensive. And do you think we could accomplish all of the above for $20 billion a year?

Dr. GRIFFIN. Yes, sir, I do, if the other criteria is met, as I often indicated in the more extensive written remarks. I do believe NASA needs an increment of funding over what they have had in real dollars. Of course it has dropped quite substantially over recent—or the last few decades. I think—I guess this is a tough—you know, the right things to be doing or I would not have listed them. They are the things that I believe the space agency was chartered to accomplish. I hear remarks from witnesses on this panel today that imply that we need to reduce or curtail space flight. It is not NASA's job to figure out how to do less space flight. NASA was chartered to figure out how to do space flight. We need to revector them so that they are working on the proper things, but they, in our view, need to be given all possible encouragement to do it.

Chairman BOEHLERT. Dr. Huntress, do you want to——

Dr. HUNTRESS. Yes. In ten years after the Augustine report, I would order it similarly. I am a space scientist, and so of course I am going to put space science or science in general, in fact, from space at the top of that list, and one of the reasons is because before we send humans to any destination we might choose, we are going to require to send our robotic spacecraft there to understand this destination and determine exactly what it is that humans can do best at that destination. Because before we send them, we are going to do the science robotically, because it doesn't require the same amount of risk and it can be done more cost effectively. But there will come a point where we run out of robotic capability and we would like humans to conduct the investigations.

So I would pick the science first and then follow in second priority with human space flight. And what derives from human space flight and the destinations choose all of the technologies you are going to need for both Earth to orbit and for getting from Earth orbit to the destination that you are going to. So I agree with Congressman Gordon's assessment of the order of technology here. And that is the way I would list them.

Chairman BOEHLERT. Dr. Koss.

Dr. KOSS. I see nothing wrong with the five recommendations you outlined from the Augustine report. I think the issue has always been the proper balance. I think right now they are out of balance in that there is too much emphasis on human space flight and not enough emphasis on the autonomous and remote capabilities. Some of the items may have to be deferred. I think Dr. Roland made some very good points. He is not advocating the end of human space flight. He is just saying we need to master low-Earth orbit before we can consider more. So, you know, keep all of those items in one's mind, but recognize that the balance has to be better struck. And be very careful of mixing the mission of one of those objectives with the other. I am a physical scientist. I am more concerned about mission to planet Earth and what happened is that mission has gotten tied in with the human exploration and development of space. And so there are astronauts that are involved in physical science experiments partly to make those experiments easier and partly for them to gain experience of being on orbit. And so that mixture, I think, is something to be concerned with.

Chairman BOEHLERT. Dr. Roland.

Dr. ROLAND. I would say that development of launch vehicles is more important than all of the other four combined, because anything we want to do in space entails getting there, whether it is automated spacecraft or human spacecraft. And until we improve our launch vehicle capability, we pay a penalty at the beginning of every mission. NASA has repeatedly said, and the Department of Defense has repeatedly said, that what is wanted—they have been saying this for 20 years—is an order-of-magnitude reduction in launch costs. And going along with that is more reliability and more safety in our launch vehicles. That is still true. And if we address that objective, then all of the other things that we want to do in space will become cheaper, easier, and more efficient.

Chairman BOEHLERT. Thank you very much. I have run out of time, but I will have Dr. Murray respond briefly, if he can——

Dr. MURRAY. Yes.

Chairman BOEHLERT.—too.

Dr. MURRAY. I want to point out that the reason we are having these hearings you have taking place now is human flight, not the NASA total program. And so the Augustine report put automated flight well above it in priority. So we now have a human flight situation, which has become a financial and political problem. That is why we need to deal with it. I think that is not solved by a heavy lift vehicle. My understanding is any heavy lift vehicle that is put together now will have to have multiple applications. You certainly don't need it for automated science that I know of. I don't know if the Defense Department has special needs with—for something that is huge that we are talking about or not. The reason it is important to think this through very carefully is there is a huge wedge at the beginning of any program once you say we have to have this new vehicle. Product improvement of the older ones is great. So I don't believe—the reason is for human flights to Mars or to other distant places, on orbital assembly is an alternative, which—out of the Space Station development has now. But that will be by far the more competitive way of doing it.

I want to mention just before finishing up on this the idea of curtailing human flight. People seem to forget NASA chose to do it itself between 1975 to 1981. There were no Americans in orbit, because NASA wanted to develop the Space Shuttle. And so following Apollo-Soyuz in 1975, there were no astronauts in orbit. They built in that hiatus of six years for a Shuttle flight in 1981. I don't see why that is such an unacceptable alternative in looking at changing the program mix at the current situation. We shouldn't just say we have to do it the way it was imagined to be done in 1983 when the Space Station was first started.

Thank you.

Chairman BOEHLERT. Mr. Hall.

Mr. HALL. Thank you, Mr. Chairman.

I agree with most of the statements that it is proper to take the time in the aftermath of a calamity like *Columbia* to determine the best path forward. And I certainly agree with one of you whoever said that—not to look for blame but to look for how we run a better program and look to the future. And the one word that keeps coming to me and one I never will abandon is safety and continue to pursue safety for the—whatever vehicle we have. And if we have another such loss or tragedy and we haven't undergone a venture starting to travel towards safety, then I dread to be a Member of Congress or to be a member of the NASA team. I think they better damn well get started on getting us some safety in the Shuttle itself. And I support the Shuttle system. I think we need to move beyond the debate of whether or not we ought to have a human space flight program. There should no longer be a question of robotic versus human exploration. Clearly both are going to be needed to explore our solar system. And Dr. Roland, you have at least been consistent. I don't agree with you, but you have been consistent through up to this time and will probably remain consistent forever like a turtle that bites. You won't let loose until it thunders, I have always heard.

SUPPORT FOR HUMAN SPACE FLIGHT

But if—I wanted to say that whatever question I ask I want you to crank into the computer the safety, the escape nodule for the Shuttle. That just has to be a part of it, and I don't see how anybody can disagree with that. With that, Dr. Griffin or Dr. Huntress, you both—exploration programs many times around since both of you have extensive experience in trying to obtain resources for NASA and for a lot of the NASA programs from a convent that has to focus on annual appropriations and what we have and what we can foresee and what we can afford. I guess my question is how would you design your program to survive an inevitable ebb and flow as we call it of Congressional funds or political support or fiscal support over the time period required to achieve the goals that you propose? Dr. Griffin, you might answer that. If not the budget, let us just say it should stay flat at a level of roughly $15 billion for the foreseeable future, could the exploration program that you advocate be successfully carried out, and if so, how?

Dr. GRIFFIN. Thank you, sir.

If NASA's budget were to remain flat, I think we can agree—have not been advisable, and if we want to do new things going in new directions and at the same time keep the budget flat, we would have to, in my view, take ourselves out of the number of commitments that we now have. These are commitments to international partners on Space Station, commitments to keep it going in the near-term, which implies the use of Shuttle and so forth. The—I would regret that, because, as I indicated in my written testimony, I believe in keeping—in the United States keeping its word. In the program of the future that I envision, the program of exploration, it would be a program that involves people from all nations. But I see the role of the United States to be the leader among them. It is very difficult to function as a leader if we do not have a history of keeping our prior commitments.

With that said, if there is to be no more money available and if we have to undertake a program to do newer and better things to make better choices, then there is no opportunity other than—there is no possibility other than closing off some of the older avenues and revectoring what we do.

Mr. HALL. Dr. Murray.

Dr. MURRAY. I want to emphasize that I think the Mars program can——

Mr. HALL. Come a little closer to the mike, if you will.

Dr. MURRAY. It is even better if I turn it on.

I think one of the defects in the national thinking about going to Mars with humans is it would try to be modeled on *Apollo*. That is not the right way. *Apollo* is a one shot deal. Enormous investments over a short time at a certain period. In the case of going to Mars, what counts for us now is that that is the acceptable destination and we are going there not to share the flag but to do something that has long-term importance. That means it could be broken up into a set of steps. The steps provide flexibility with budget aspects, also allowing for unpredictable things in the future.

For example, this whole issue of on-orbit assembly needs to be understood. That may change the launch vehicle requirements significantly. That is a task. Another thing we could stop right now is we have a large automated human—automated program of exploring Mars scientifically, greatly. There are enormous resources going into that very effectively. There is no formal leaping of that program to the fact that we are also thinking we would like to have human landing flights there in the future. We call that the Mars outpost concept, to identify places from what we know now would be suitable for human landings and the—with Mars resources onwards with the idea of implementing communications, data handling, mobility, and maybe even chemical processing of materials to the—so that by the time we really get ready to go we know where we are going and some of the resources are already there. That cuts down the cargo requirements and assures a long-term situation. I can—there is a long list of these things we can go through. But that kind of thinking, how do you break it up into pieces that are interesting, each one of which is affordable, is what is lacking so far and we need your help in putting pressure on the Administration and NASA to begin to think like that.

Mr. HALL. Dr. Huntress, my time is almost up. That might be a red light there, but maybe it is just orange. May the gentleman have another maybe half a minute?

Chairman BOEHLERT. Sure.

Mr. HALL. All right. Dr. Huntress.

Dr. HUNTRESS. Well, I do agree with Dr. Griffin, and if we keep NASA a constant at $15 billion, even assuming that you add inflation into that, that we really have three choices. One is what Dr. Griffin talked about, which is, okay, we need a new vision and we are on the wrong path and let us re-engineer what we have done. We have got to give up our commitments to our foreign partners. We have to do something other than Station and Shuttle. Or the other path is that we continue business as usual, because that is all that we can afford at the moment. And that is unfortunate, because at some point, we are postponing what the public really wants us to do, and they will have the tendency to—the current infrastructure. And so I think we need to really think what path we want to go on and what it is really going to cost. I do believe that we can put a program together that is progressive, that goes step-by-step, that doesn't require an *Apollo*-like spending curve, that will require a minimum increase to the annual budget of NASA over a long period of time. I think that is possible.

Thank you.

Chairman BOEHLERT. The gentleman's time has expired.

In your testimony, Dr. Huntress, I put exclamation points after this one sentence of yours. "There is a growing chorus of leaders inside and outside of government concerned that NASA's post-*Columbia*-investigation posture is business as usual." Could you expand upon that a little bit and then we will go next to Mr. Smith?

Dr. HUNTRESS. Yes. By business as usual, I mean we just continue on our current path. We upgrade the Shuttle, we fix the current problem with the Shuttle and complete the Station, which I think to honor our *Columbia* members, we really must do in the long run. But we need to look beyond the Space Station. What is going to come beyond that Space Station? That is not business as usual and that is what requires a new vision for what we are going to do in space.

Chairman BOEHLERT. Thank you very much.

Mr. Smith.

Mr. SMITH OF TEXAS. Thank you, Mr. Chairman. Thank you, also, for convening this hearing and also for having such expert witnesses today. I also want to thank Mr. Rohrabacher, who is the Subcommittee Chair, for allowing me to go ahead of him to ask some questions, because I am late to another appointment.

Dr. Koss, before I get to the first question, I notice in the last line of your resume you say you are a lifelong Red Sox fan, approximately a one-hour drive from Fenway Park——

Chairman BOEHLERT. The gentleman's time has expired.

Mr. SMITH OF TEXAS. I suspect you made a big sacrifice to be here today, because you missed the game last night, is that correct?

Dr. KOSS. That is correct, but the pilot kept us informed on the airplane, but the crowd didn't cheer until it was at least a three-run lead.

Mr. SMITH OF TEXAS. We know where the Chairman of the Full Committee is on this, so we won't pursue this subject any more.

GOALS

My question really for every witness today is this. It seems to me that we are in some sense drifting when it comes to what do we do in space and when do we do it. We don't have a vision. Dr. Huntress, you referred to this both in your testimony earlier and in response to a question a while ago. And I think we would benefit by having a specific goal. And really, my question to you all, each one of you, is if you were advising the President, what would be your recommendation to the President to announce in a major speech as to what our goal in space should be over the next five to ten years. Dr. Roland, for you it might be launch vehicles, developing them. Dr. Huntress, for you it may well be at least initiating if not completing the mission to Mars. But I would like to just ask each of the witnesses what would be your advice to the President either for a vision or for a goal as to what we should be doing in space over the next several years. Dr. Griffin, if you will go first.

Dr. GRIFFIN. In the next decade, I would want to see the establishment of a lunar base and the development of the technology necessary to support that. That includes a heavy lift launch vehicle. I would want to see the necessary robotic program undertaken to pave the way for human landings on Mars, very much in keeping with Bruce Murray's concepts.

Mr. SMITH OF TEXAS. Thank you.

Dr. Huntress.

Dr. HUNTRESS. Congressman, I would have one minor change to the challenge here, because I do believe a decade is far too short a time scale for having a vision for this country's space program. And so I would recommend to the President that we establish a goal to establish a permanent human presence in the solar system with a specific stated objective, to establish human presence on Mars by the middle of this century, and that the near-term actions required to do that would require some re-engineering of our current path in getting to Earth orbit.

Mr. SMITH OF TEXAS. Thank you.

Dr. Koss.

Dr. KOSS. Give me an idea of near-term.

Mr. SMITH OF TEXAS. Ten years. Ten years.

Dr. KOSS. I think it is premature to have a vision right now. I think the Chair correctly pointed out that the vision is blurry. So I think a panel like this and others should go on with other witnesses and other discussions to focus that vision. There needs to be a common ground forged. And without common—forging that common ground, I don't think any vision is appropriate at this point.

Mr. SMITH OF TEXAS. Dr. Roland.

Dr. ROLAND. Mr. Smith, as you guessed, I would recommend launch vehicle development, but I would phrase it in terms of the access to space. Space has enormous potential for human applications, which we are unable to exploit now because it is so expensive and dangerous to get there. And if we could open up that access, it would open up countless opportunities.

Mr. SMITH OF TEXAS. Thank you, Dr. Roland.

Dr. Murray.

Dr. MURRAY. Thank you.

I would say what we need is a destination, a place that is worth risking human life and a lot of money that is imaginative and uplifting. And Mars is clearly that. So the President, if he really wanted to achieve the reversal of the decline we are in, he would first have to say that is where we are headed. I commit to the United States of America in that direction. We need that to be international. We need, therefore, to involve others. But it would have to have, therefore, some budget request to go over to make it believable, but it wouldn't have to be a lot. But I think the very fact that he has declared that would change an awful lot of things, including NASA's own attitude towards itself, which is a major problem here.

Mr. SMITH OF TEXAS. Thank you, Dr. Murray.

Thank you, Mr. Chairman.

Chairman BOEHLERT. Thank you very much.

Mr. Gordon.

LUNAR EXPLORATION

Mr. GORDON. Thank you, Mr. Chairman.

I—as I had mentioned earlier, I want to discuss some of the pros and cons of a—as you—as Dr. Griffin pointed out, a lunar outpost. You have some that say—would say, you know, done there, been that or done there, done that. And that really isn't a great vision. There is—as someone pointed out earlier, whether we like it or not, and I would say most of us on this committee don't like it, we are not going to have a significant increase in the budget. You can talk about us not having vision or not being—having courage, you know, all day long. But the fact of the matter is, that is what is—you know, we are not going to have a significant increase in budget. Hopefully we are going to see some increase.

So we are going to have to put it in that perspective. And again, I would like your thoughts as to the benefits, or cons, of having a lunar outpost, similar—to ensure as we did Antarctic at one time, the lessons that could be learned there. And it being a potential kickoff through those lessons to maybe a more aggressive vision of going to Mars at a later time.

Dr. Griffin, you started it. Why don't you tell us what you think?

Dr. GRIFFIN. Thank you, sir.

Let me first say that if I implied it in my own remarks—that is absolutely wrong. I agree with Wes, my former NASA colleague, that the vision needs to be much longer-term than that and is really nothing less—in my written testimony, the vision is nothing less than the permanent human occupation of the solar system. Now in the next decade or so, the things that we need to do first, my ordering of that might be different from some others. I believe that going to Mars without——

Mr. GORDON. Sir, I have got a short period of time, and I would like to focus the comments on the pros and cons of the lunar colony.

Dr. GRIFFIN. The pros in support of the lunar base would be that that is where you learn how to survive for long periods of time on other planetary surfaces and be only three days away from home when things go wrong, as they inevitably will. The cons are that it is money spent in a direction not as interesting as Mars.

Mr. GORDON. And that is not in the same direction?

Dr. GRIFFIN. I believe they are in the same general direction, but there will be things one needs to do, return to the Moon, that one would not need to do to go to Mars.

Mr. GORDON. Well, are there other resource values?

Dr. GRIFFIN. I think so. We need the extraordinarily interesting place to set up both radio and optical telescopes.

Mr. GORDON. Would anybody else like to comment on that topic?

Dr. MURRAY. Well, I would like to comment that the—over the many decades that these debates have been going on, the astronomical community has been very permanent towards any kind of facility on the Moon. I note because I tried it one time. Almost all of the—they do much better off having a system out in deep space itself, not tied to the Moon. So I think it would be very difficult to build that as a case. I think the case for it as a stepping stone to Mars has some merit, but to the extent that it is financially a significant diversion, I don't think that will fly. So I think that—go ahead.

Mr. GORDON. I mean, I—it just seems to me that if we are going to go to Mars in 30 or 40 years or whatever it might be, that we may want to show a little something for it on the way to—so the taxpayers might have the courage to continue to pay the bill.

And let me ask what is going to happen if China decides that they are going to have a ten-year goal to go to the Moon and set up a base, not a base but an outpost, excuse me, or and Russia says in 15 years. Are we going to say good luck or are we going to try to catch up at that time?

Dr. ROLAND. My suggestion is we could sell them the Space Station. But that is an option for us now because we are at a point where supporting the Space Station really is——

Mr. GORDON. Okay. I don't want to get into all of that. I want to talk about the Moon. You know. I don't have a whole lot of time.

Dr. ROLAND. Yeah, but my whole point is getting to low-Earth orbit is how we can do anything in space whether it is the Moon or Mars or any other scientific experiments, and that is what we need to concentrate on that will make all of the——

Mr. GORDON. I have got a short period of time. Would anybody else want to comment on the pros and cons about going to the Moon? Yes, sir.

Dr. HUNTRESS. Yes, Congressman Gordon. I think the Moon is sort of an off ramp on our way to Mars. And there are some useful things to do. There is some good scientific work that needs to be done there. Europe, Japan, China are all interested in Mars because they have never been there, and so they tend to focus on that. And so the only thing I worry about is that if we design a system to go to the Moon, that is all that we will be able to do. We need to design a system that can go to Mars and use it to go to the Moon to do whatever we need to do to enable Mars exploration.

Mr. GORDON. Anybody else want to say something, and then I will——

CHINA

Dr. MURRAY. Yes, I would want to challenge the presumption that because China got its first astronaut or cosmonaut or whatever it is in space yesterday that this leads immediately to a very big expansion. It is 40 years after this was done by the U.S. and Soviet Union. I am surprised it hasn't been done by Europe and by Japan by the way who could have easily. They had the technical capability. And the reason wasn't that important. The reason it is important in China is because it is obviously political, both domestically and especially in Asia I think, which is fine. I am glad they have done it. But we can't necessarily extrapolate from that that they are going to repeat the——

Mr. GORDON. Yeah, but the hypothesis was that if they said they were going to do this in 10 or 12 years, would we not challenge that.

Dr. MURRAY. I would—we did that long ago.

Mr. GORDON. Yeah.

Dr. MURRAY. We have got to do new things that we might build admiration with both our populous and the others. To go back and get drawn into 30 years ago rivalry is crazy.

Mr. GORDON. Well, I think there is a difference between going to the Moon, touching base and going home than setting up an outpost. Did you—yes, sir?

Dr. KOSS. Returning to the Moon may have some small advantages requiring physical sciences to be enabling technologies. But in terms of a location for the physical sciences to benefit, it has nothing to offer.

Mr. GORDON. Thank you for your laxity there, Mr. Chairman.

Chairman BOEHLERT. Thank you very much.

I hate to do this but I would like a quick yes or no. The value of the investment, is it worth it to talk in terms of an outpost on the Moon, Dr. Griffin?

Dr. GRIFFIN. Yes.

Chairman BOEHLERT. Dr. Huntress.

Dr. HUNTRESS. Yes.

Chairman BOEHLERT. Dr. Koss.

Dr. KOSS. I don't know.

Chairman BOEHLERT. Dr. Roland.

Dr. ROLAND. No.

Chairman BOEHLERT. Dr. Murray.

Dr. MURRAY. No.

Chairman BOEHLERT. Wow. There is a—two and two and one that is—you have got three, Mr. Gordon.

The distinguished gentleman of the Subcommittee on Space, Mr. Rohrabacher, better known as the governor-elect's friend.

Mr. ROHRABACHER. Did you get that blurred picture more in focus for us by that last question? My gosh.

Mr. Gordon, your question reminds me of Robert Heinlein's famous saying, "Once you are in the low-Earth orbit, you are halfway to anywhere else in the universe." So whatever our goals, whatever we talk about today, Mr. Chairman, having been on this subcommittee and spent some time looking at this issue, and having been in the White House prior to that and looking to space issues, that hasn't changed all of these years. I think Robert Heinlein must have written that 25 years ago. So does anyone on the panel disagree with that?

PRIORITIES AND FUNDING

No? So Mr. Chairman, it is clear—excuse me, I have got a cold, obviously. But what is clear, then, is that whatever goals we set, the first step is what, is finding a way to get into low-Earth orbit at a cheaper rate. So I have been—let me ask this question to the panel. All of you, it seems, except, perhaps, Mr. Roland, would like an increase in the budget of NASA as we have it today rather than a flat budget and have a more visionary program. At what level do you want that? Mr. Huntress didn't exactly tell us exactly how much that was. How much would you suggest? And would you support that funding coming out of other programs that are being financed by the United States Government in terms of science research in American universities? That will tell whether you really believe in it or not. Mr. Griffin first and then——

Dr. GRIFFIN. I indicated in my written testimony to allocate to NASA on a steady basis was around $20 billion.

Mr. ROHRABACHER. That is $5 billion more——

Dr. GRIFFIN. $5 billion more a year. I think we should not have a big *Apollo*-style reinvestment.

Mr. ROHRABACHER. So you believe that—you would accept that that money would be coming out of the research project money from major universities? That would be worthwhile, taking money from science research in our major universities and putting it there? $5 billion a year.

Dr. GRIFFIN. I don't know that that is who I would take it from, but——

Mr. ROHRABACHER. Well, this—that is what you know about. The other places that you might not—take it from you might not know about. They can take it from places they don't know about. So is it more worthwhile to do it that way?

Dr. GRIFFIN. If that is the way it had to be, then that is the way it would have to be.

Mr. ROHRABACHER. Thank you.

Dr. Huntress.

Dr. HUNTRESS. I agree with Dr. Griffin in the amount that would be necessary for that extra $5 billion a year. And one can build up to that. You don't have to add it all at once.

Mr. ROHRABACHER. Would that be enough to take it——

Dr. HUNTRESS. I believe it needs to be an additional complement to what this country does in exploration. We have targeted one area, which is scientific research, and I would not take it from there. No.

Mr. ROHRABACHER. So the answer is you don't believe it should be $5 billion more a year if it has to come from something you know about?

Dr. HUNTRESS. I believe it should be an extra $5 billion a year, but coming from the Nation's scientific research project——

Mr. ROHRABACHER. Okay. There you go. You don't believe it then. Yes?

Dr. KOSS. Obviously, I have a university research bias, so I certainly don't believe the money should come from university science research funds. In addition, I don't think it is healthy for the sciences——

Mr. ROHRABACHER. Okay. Mr. Roland.

Dr. ROLAND. The United States spends more in space than all of the rest of the world combined. We spend plenty of money on space. The whole question is the pace of what we are going to do, and I think we can hold the budget steady and achieve our goals, perhaps, over a longer term.

Mr. ROHRABACHER. Okay. Very well.

Yes?

Dr. MURRAY. That is a very good question. And you are getting to the heart of it. I think the problem is we are spending $7 billion a year presently on human space flight without adequate return. I think we should restructure that program with an idea of diverting some of those funds to longer-term things.

Mr. ROHRABACHER. All right. I—that has helped. I have learned in my tenure in office to find out if somebody really believes in these funding proposals they are making is to ask them to juxtapose it to something else they think is of value. And I would suggest—I—you know, no one is here to hear my suggestions today.

But let me ask about just one—a question about propulsion, and I do believe, as I say, that propulsion is the most important issue to get us wherever else we want to go. Would nuclear-powered engines and the development of this help us get to that low-Earth orbit or is that just while you are in space? Just very quickly answer that way down the line.

Dr. GRIFFIN. Space nuclear propulsion is for in-space use.

Mr. ROHRABACHER. But could—used to get us to low-Earth orbit?

Dr. GRIFFIN. I—you might want to——

Mr. ROHRABACHER. All right. Mr. Huntress, would you say anything on that?

Dr. HUNTRESS. Well, I agree that nuclear propulsion is the right way to go for in-space propulsion but not getting into Earth orbit.

Mr. ROHRABACHER. Okay. Mr. Koss.

Dr. KOSS. I can't answer. I'm not a rocket scientist.

Mr. ROHRABACHER. Mr. Roland.

Dr. ROLAND. I don't know with technical confidence, but I would be worried about the public relations and safety issues.

Mr. ROHRABACHER. But what about the technical end of it? Is there a potential——

Dr. ROLAND. I am just not technically qualified.

Mr. ROHRABACHER. Okay.

Dr. MURRAY. I think the reason is that nuclear propulsion translates into relative low thrust——

Mr. ROHRABACHER. Right.

Dr. MURRAY.—which is best——

Mr. ROHRABACHER. Well, I have heard some news recently that indicated that there might be some other way to do that.

All right. Well, thank you all very much, and thank you, Mr.—first of all, I want to thank the Chairman for calling this hearing. And we need this discussion. And I thank you very much for putting together such a distinguished panel for us to base our future considerations on.

Chairman BOEHLERT. Thank you very much, Mr. Rohrabacher.

The Chair recognizes Mr. Lampson.

Mr. LAMPSON. Thank you, Mr. Chairman.

Monday we celebrated Columbus Day. 511 years ago, Christopher Columbus traveled those uncharted waters across what we now know as the Atlantic. I wanted to comment about the comment, and I am not asking a question right now. It would be interesting to know the number of lives that were lost per boat as they came across and wonder if that would have been considered by Amerigo Vespucci as to whether or not he should follow in that path. It is something worth our consideration.

Any time we do exploration, there is going to be some risk. I pray that we never get to the point where we fear the lack of some life for what we might gain in the future for overall life. I also welcome China into the space flight club. I think it is great that they have done what they have done. I think it continues to increase the knowledge and awareness of our involvement in space worldwide.

History has shown that great nations explore. The United States must not turn its back on human space exploration at this critical time. We must return to Space Shuttle—or the Space Shuttle to flight and complete construction of the International Space Station. And at the same time, this Administration and this Congress must provide the American people with a vision and a concrete set of goals for the Nation's human space flight program. It is clear that China has set goals and has goals that have been set by its leadership. And we need the same.

THE SPACE EXPLORATION ACT

And with that being said, I would like to ask both Dr. Griffin and Huntress if you are familiar with the Space Exploration Act that has been introduced both in the previous session and in this year. And if you are, would you please make some comments about it as to how it fits in with accomplishing just those things, the goals that we need to have and what we can get back in our involvement in space?

Dr. GRIFFIN. Yes, sir, I did read it, not within the last few weeks, so—but I thought it was deliberate. I am very much in support of it. It is in the direction that I truthfully believe we should go. And the only thing I would like to see is a little bit more of an effort to set specific time horizons with the funding you are planning to implement them.

Mr. LAMPSON. Do you consider it—let me ask this. Do you consider it to be micromanaging of NASA?

Dr. GRIFFIN. Possibly a little, but then again, many times that is needed in order to get going in a path different from where we are.

Mr. LAMPSON. Thanks.

Dr. Huntress.

Dr. HUNTRESS. First of all, I think it is very important, because what it does is to get the sense of the Congress's representatives of the public squarely on the record as to what it believes this nation's space program ought to really do. And I—something like this should be a bipartisan clarion call for this country's space program. I see a lot of this bill that I really like. I support it because it is thankfully consistent with the kinds of future vision, you know, that I have been thinking about for these last several years. It speaks about a commitment to the future for human space flight. It talks about both human and robotic means to do that. It identifies margins for the ultimate goal but with a stepping stone approach for progressive and a more affordable program. It talks about scientific exploration as the basis for it, something that we need for an inspiration to our youth. If I had to find some criticism, it would be that I think the time scales are, perhaps, a bit prescriptive as well as some of the processes it talked about for the Administration.

Mr. LAMPSON. Congressman Smith asked a while ago about advice for the President. Would this be reasonable advice for the Congress to be able to take these kinds of steps and would that energize our nation enough, perhaps this government enough, to find the kind of attention or statement that he may be looking for a while ago for the President? Anyone? Either of you two, particularly.

Dr. GRIFFIN. I think the language—I would say it is one letter—than what is the appropriate—especially coming from the Chief Executive or, you know, a bipartisan consent from the Congress. I think that the letter of detail is, again, as Wes said, I likely agree with what is there, but it needs to be—in order to try and capture it, I think, as a national vision that is understandable.

Mr. LAMPSON. And then let me ask this about what happens. If you design—how would you design your program with the inevitable ebb and flow and political support over the time period required to achieve the goals that you propose? And that is part of what I think our problem is now. That has changed clearly through Administrations in the last many years.

Dr. HUNTRESS. I think the way you do this is by designing a program that is a little bit more immune to that than the one we have now. And the way you do that is by having intermediate destinations, a progressive approach in which you build the infrastructure slowly and more progressively instead of all at once so that you can adjust the time it takes to construct that infrastructure depending the annual budget process.

Mr. LAMPSON. Thank you all. And Mr. Chairman, I would ask that all of my colleagues take a deep consideration to the Space Exploration Act. Is—it may be much—in the direction to achieve that we have had in this discussion this morning, and I thank you very much. I yield back my time.

TECHNICAL CHALLENGES

Mr. EHLERS. [Presiding.] The gentleman's time has expired.

The Chair has asked me to take over, because I have the next question anyway.

I always hate to be a wet blanket, because I like to be an optimist, but I am a little dismayed by some of the optimism I see here. I think there are a lot of problems that have been glossed over, and we should take a look at those.

First of all, one thing I gathered from this as most of you regard the Space Station as not particularly useful for our long-term objectives. And someone said we shouldn't have done it at all. Well, that is hindering our efforts. Perhaps we ought to rename it the Albatross because we have to take care of it, we have to send crews back and forth, and that is going to consume a lot of our resources. But if our long-term goal is interplanetary exploration, it may not be that helpful. All right. I may be overstating it. But over at the other issues, the discussion on going to Mars in which the panel is precisely equally divided, Dr. Griffin, for example, you said human—your goal that you believe—or our goal should be human flight of the solar system and beyond. Let me just comment a bit on the comparisons we have had to Columbus. I don't think it is a good analogy at all, frankly. First of all, Columbus was not a scientist. He was trying to make money by finding a shorter trade route. And if he were much of a scientist, he would have known that the diameter of the Earth had been calculated some time before and the distance he is prepared to travel is far too short. However, he was lucky, as many scientists are, and quite a few businessmen, and he stumbled across something that was even better than what he had expected or what he was looking for. But settlement of what we now call the rest is far different than settlement of planets, because we have a huge number of resources here, better resources, in fact, from—than the country from which they came. No support was needed, other than the food, to transport the crew. They didn't need energy to get here. The used the wind's energy.

I understand you know what is involved, but the general public thinks that we went to the Moon and the next step is Mars. The Moon is just a stone's throw away compared to Mars. It is a very, very long trip. And I personally don't think we are going to get there without, first of all, a—completely better sources of energy, far better sources of propulsion, and a method of induced hibernation for humans unless we are going to try—it might actually be easier to make bears and other things that hibernate into intelligent beings than it would be to make humans into something that can hibernate. But the energy involved in putting individuals into interplanetary travel is immense. And the human persistence requirements are immense. You combine the two, and it is a very long, very expensive, very difficult journey. I am not saying it can't be done.

But I would also say that I don't think it is ever going to be done without an international effort, because I can tell you the public is not willing to spend that amount of money to put one person on Mars. And unless there is substantial return. Intermittently I think we can put together the forces to deal if we can cooperate. So I would be very interested in hearing the comments that you would like to make about that pessimistic view. I am not saying we shouldn't explore space. I think we should, but having—placing a human being on Mars I think might be as much of a limiting factor for our efforts to explore space as having the Space Station up there as limiting our efforts to go beyond and get—do experiments out of Earth orbit.

So let us—we both have been going that way. Let us switch the other way around. Dr. Murray.

Dr. MURRAY. Thank you.

In terms of propulsion to get to Mars, we will send an automated probe. It takes very little energy beyond getting into orbit, getting to high orbit, to go to Mars, or even the Moon. There is not much. It is coasting most of the way. You have to choose the right time to go so it is an easy coast. So I don't think that—I don't see that as a showstopper itself. It is true the—that the——

Mr. EHLERS. Just give me a minute to clarify.

Dr. MURRAY. Yeah.

Mr. EHLERS. And we are talking not so much the energy to get there but the—it—the loss of energy, potentially, you have to take a—to get to the surface of Mars and to get back off the service and to get started on the——

Dr. MURRAY. Mars is the one planet that has carbon, hydrogen, oxygen, and nitrogen easily available. Greenhouses can work. There is solar energy, although presumably some nuclear power would be available in the future. It is the one place where you can go where you can grow food. It is the one place where you can go take some of that ice we found break it up and make hydrogen oxygen for propulsion systems to come back. That is the kind of thinking that has been going on over this long hiatus of exploration. So I think what is lacking is that we haven't had an effort under government sponsorship to really look at how you could do this, other than the *Apollo* way. I think that if it is difficult, as you would extrapolate from the *Apollo* experience, it does take breaking the pieces, as Wes has said. It does take believing in that goal. I mean, if that is not, you know, the goal, then it is not going to happen. But I don't think it is that. I don't think it has to cost a bundle if we do it in modules in time. I think it will be popular if it is done the right way. But we have not had a chance to develop and put forth before you a program like that.

Mr. EHLERS. Dr. Roland.

Dr. ROLAND. I have seen estimates of hundreds of billions of dollars just to send one mission of humans there, and that is not to build up an infrastructure on Mars and start to culminate it and build a base where you can begin to exploit growing food and getting fuel out of there. So I think the cost would be enormous and it begs the question of what would a human outpost on Mars return on that investment?

Mr. EHLERS. Dr. Koss.

Dr. KOSS. I think your assessment is correct. And as much as I am a fan of a larger mission for NASA, I hate to see a single mission rob the other missions that NASA does that only NASA can do. And I speak most particularly to the field that I work in in these laboratory sciences on orbit. And on a side note, I might mention that on your Columbus analogy, it has been speculated that Columbus knew the size of the Earth, but he misrepresented it to get better funding.

Mr. EHLERS. Which proves he wasn't really a scientist, because a scientist would never do that.

Dr. Huntress.

Dr. HUNTRESS. First of all, I agree that this should and must be an international enterprise. I agree that no one single country is likely to be able to afford such a venture, and it should be international not just on budget reasons, but for good human reasons and societal reasons as well. The hundreds of billions of dollars that Dr. Roland quoted is the 1989 number for a program designed by NASA to be done in the *Apollo* style. And that is certainly not the way that we really should do it and we probably won't do it that way. It will take much less if it were done in a progressive way. And I agree with Dr. Murray that the way to do it is we use in situ resources, what I would envision as single humans there quickly and fast on chemically propelled systems, sending their cargo separately on efficient electrical systems and using in situ resources on the surface of Mars to create the resources they need on the planet and to prepare fuel for their return.

Mr. EHLERS. Actually—Dr. Griffin.

Dr. GRIFFIN. I agree wholeheartedly with the technical points made on the previous question, but I would point out that if it takes hundreds of billions of dollars to go to Mars, then we need to get new project managers, not a new destination. And with the nuclear experience that we, the United States, have, we had a space qualifiable nuclear thermal propulsion system 30 years ago and terminated the program because we were not, at that time, going to Mars. Transit time would have been two to three months. So I just do not agree that it is particularly difficult to do that. And again, I would probably not—if I were going to do it, I would use spinning spacecraft. As far—and again, I can only—the plan for doing it should be one that utilizes to the maximum extent replacement of the hardware needed to sustain people. We should do the program intelligently. I think that can be done. One can find—I think we can do better than that.

Mr. EHLERS. I think everyone should realize what a major, major step this is, far greater than anything we have ever done as a nation. And I can—I just want—politically, it is going to be very, very difficult to get that support even within the scientific community. Many of those members will react the way they did to the SSC saying for the amount you are spending on that we can do 10,000 experiments in the life sciences that will be more important. So the real—I think it is politically unless it is very long-term, and in fact, you do develop much better methods of transportation and propulsion and they are very well thought out plans for doing it.

The—we have all heard the bells. We are very Pavlovian in the Congress: the bells ring, we vote. Now we have, what, three votes. We have three votes, which means it will be at least a half-hour. And we will have to recess at this point. And others—I assume others have questions. Okay. We will try to get through one more questioner, and then we will go vote and there should be sufficient time for you to run downstairs and get some lunch while we go vote. And we will be back as soon as possible after the third vote.

I am pleased to recognize the gentleman, Mr. Bell, Congressman Bell.

ROBOTIC EXPLORATION

Mr. BELL. Thank you, Mr. Chairman.

I might have to explore this subject, if I could on the robotics that several of you commented on during the course of your testimony. First of all, Dr. Huntress, you pointed out that you can run out of robotic capability. And if you could just explain how that would occur, I would like to hear your explanation.

Dr. HUNTRESS. Well, you know, first of all, the advantage of robots is that they are inherently expendable. You can use them where humans are unacceptable, the risks on humans are unacceptable. The problem with the balances of—the methods of remote control for these robotic systems are often cumbersome and delayed. And so we should use them where there is no clear advantage for human beings. And the advantage, however, that humans have is humans are ideally suited to tasks that require very complex, physical articulation, expert knowledge, judgment, and versatility, kind of like in the Hubbell Space Telescope servicing missions. And they are ideally suited for intensive field study, you know, where you need the real time observation, hypothesizing, testing in real time, synthesizing real construction like in the geological investigations of *Apollo 17.* So you have to figure out where that line is in an intelligent basis.

Mr. BELL. And I guess the problem I have is that when this conversation begins, a lot of things people want to talk about in mutually exclusive terms that you either choose robotics or you choose manned space flight, but you really can't have both. And I take it from what you are saying is that you definitely believe we need both?

Dr. HUNTRESS. Absolutely. In fact, there never has been one or the other. The *Apollo* program was heavily supported by robotic missions prior to sending a man to the——

Mr. BELL. And let me follow up with you, Dr. Roland, because you talked about your fear that the culture of NASA, perhaps, led to some of the problems and certainly that has been commented on and——

Mr. ROLAND. Yes, quite obviously.

Mr. BELL. And, sir, are you suggesting now that you think that it—we should have mutual exclusivity, that we should solely focus on robots and move completely away from manned space flight because of the dangers involved?

Mr. ROLAND. No, I think Dr. Huntress has it right. We need a balance of—I guess we may differ, I am not sure, we haven't spoken about it enough, but I think I am looking for that balance to be more automated, remote and robotics, and I find that a lot of the science missions that were headed toward the Space Station were going to be autonomous operating experiments, but they were going to have to have human-enabled capability to absolutely be moved from the Space Shuttle to the Space Station. But they weren't going to have humans involved in their operation, and so that is sort of a silly use of human capability, and so I think I want to eliminate the silly and unnecessary uses.

Mr. BELL. But not eliminate it altogether.

Mr. ROLAND. Not eliminate it.

Mr. BELL. Okay.

Mr. ROLAND. Or eliminate it where it is absolutely not needed.

NASA CULTURE

Mr. BELL. All right. Well, I just wanted to clarify that, because I am—I think it is important for the basis of the discussion going forward, and Dr. Roland, your fear seems to be that—you talked about returning to business as usual, and I am curious, I would assume you have had an opportunity to look at the CAIB Report, and if the recommendations made in that report are followed, then wouldn't you agree that it won't be business as usual?

Mr. ROLAND. Excuse me. If they are thoroughly followed. I think there was a possibility, that is right, but remember that they are attempting to do the same thing that the Rogers Commission did, and my concern is what is really required is that—is whatever everyone is speaking of, a change in NASA culture, and that NASA revealed that its culture was unchanged in its response to the investigation. In other words, even before the investigation had reported, it was establishing a date when it was going to resume Shuttle flight operations. It suggests that it views the accident and the resulting reforms as just impediments to getting back to the same thing it was doing before. That is what was alarming to me.

Mr. BELL. And did I understand your testimony correctly that you really do believe that we should move almost completely away from manned space flight?

Mr. ROLAND. Until we have a better launch vehicle, because then, we can put people in space more safely and far more economically than now. It is a cost issue. For example, on what you were asking about space science, if you give me the same budget and say I want to do this science, I am going to get much better science, much more science, out of automated spacecraft than anyone can get out of a manned mission, even though the astronaut in situ had some marginal advantage, I can send four or five probes for the cost of one manned probe, and I can just do many more things.

Mr. BELL. My time has expired.

Chairman BOEHLERT. Thank you very much. We—here is the situation. We will recess for a half-hour and we have got a couple more votes—we will be back, and I am sorry to inconvenience you, but it is the way of life here on Capitol Hill. We are subject to the bell.

[Whereupon, at 12:03 p.m., the Committee recessed, to reconvene at 12:45 p.m. the same day.]

Chairman BOEHLERT. Just let me explain what is happening, and this is frequently the case when we are interrupted with unplanned activity on the Floor, a series of votes, as we have just had, then other Members, their schedules get all screwed up and they have got four other things they have to go do, thus you get fewer back for the second round. We haven't even completed the first round, but we have got to continue, and Members will come in and out and you understand the whole system. Dr. Gingrey.

EFFECTS OF ZERO-GRAVITY ON HUMANS

Mr. GINGREY. Thank you, Chairman. Thank you, and I agree with you, there are a lot of other things happening and things that I need to be at, but I definitely wanted to come back and ask my question. As a physician member of the Committee, I am particularly interested in this question as some more people said it, a multiple part question and anybody that can respond to it, I would appreciate it. Given the debilitating effect of zero-gravity on human physiology, bone loss and—et cetera, are long-term manned space missions realistic, and are we close to understanding or creating technologies for life support that would make a long-term manned space mission feasible? What evidence or data do we have that the human physiology programs encountered on long duration space missions, such as Mars, can be solved, and how long do you estimate it would take to fully understand what is required for long duration human space flight missions to a destination such as Mars? Have we learned anything from the Space Station? Is that the only place where we can get the information that we need in this area? I know that is a lot, but you get my drift, and again, any one of the five, maybe all of you, could respond to that, I would appreciate it.

Dr. HUNTRESS. First, Congressman Gingrey, I am—the Space Station—in my mind, the utility of the Space Station is rather singular, and that is to learn how humans how humans can live in work in space for these long duration trips. That is the, in my view, the real value of the Space Station, and almost for nothing else. Can we—these flights, I think so, and long-term flights, there is only really two risks. They are radiation hazard, from solar outbursts, and the debilitating effects of low gravity. This latter one is—can be readily taken care of by providing a spin to the spacecraft and not have a lot of effect, at the immediate expensive of—it costs some mass to do that, but that will ultimately end up being the way to do it. If we don't find ways on the Space Station that don't require spin. The radiation hazard is the harder one to solve, because it requires some kind of shielding, which I am sure can be addressed in some way. I don't see any stumbling block on our way to these long-term space flights.

Dr. GRIFFIN. I would agree with that, and I would add the additional comment that the zero-G is not really the issue. First of all, the anecdotal experience would suggest that more recent crews have sort of ameliorated the bone loss by proper amounts of exercise and being very diligent with it, and there may be other countermeasures. Even if they don't come true, as was pointed out a couple times today, spinning the spacecraft on the way to Mars or wherever is a countermeasure for zero-G. The interesting question that we have is how does the body perform in fractional G, because when you get to Mars, you are going to have to live there for presumably extended periods of time in one third G. The question that has not been settled, cannot be settled on Space Station and is of interest is, what is the body's long-term adaptation to a fractional amount of a G?

Mr. GINGREY. Doctor, excuse me for interrupting, but I think basically, that is the question. That is the question, not your zero G, but fractional G over a long period of time.

Dr. GRIFFIN. We don't know the answer and we don't have a practical way to know the answer until we really try it out. I mean, I cannot think of a good way to put crew in a one sixth or a third G environment that doesn't involve going to the planet where those things are.

Mr. GINGREY. And Dr. Murray.

Dr. MURRAY. I think we have to go—remember, unlike what we have been doing in low-Earth orbit, this is exploration, like *Apollo* was. There are many risks, and a lot of which can be analyzed to death in advance. The one you mentioned, which is what is the effect of one third G is certainly a risk of disorientation, probably going to have to allow a fair amount of time to adapt on the surface, but it is not nearly as high as the risk of just trying to land there in the first place. I mean, if you look at it rationally, and so I think we have got to get away from the sort of Shuttle era mentality, which is to make it routine and all that, to the fact that we want to go back to exploration, and of course, that is going to entail some risks. The Russians did fly cosmonauts 300 to 400 days several times successfully on Mir. They didn't do as much control by medicine as we would like, but they did, it worked, and so I think that this is not nearly so unknown as some of the other things we have to deal with.

Mr. GINGREY. And Dr. Koss.

Dr. KOSS. You know, the issue you raised about how human beings do on orbit or in apparent weightlessness is important enough that I really, in my statement, and what I try to testify to is be very clear that I said that it is the—all physical science experiments are all experiments, save those on human subjects. There is probably no substitute for having a human subject in that condition to understand what that does, and so that obviously can't be automated, but all of the other physical science experiments can be.

Mr. GINGREY. Dr. Roland, did you have something?

Dr. ROLAND. I don't address that, because it is outside my technical competence, but I lose track of what the purpose of a Mars mission is. If it is just exploration to find out about Mars, we are better off sending automated spacecraft. If it is to establish a human outpost there, then your question is pertinent and we need to address it.

Mr. GINGREY. All right, Dr. Murray.

Dr. MURRAY. I would want to—I feel that issue warrants a little more discussion. The purpose of sending humans to Mars is not to do science. It never should be. They might supplement—the purpose is to find out whether humans can operate on Mars effectively and whether that is something that really sets a pattern for what the future might hold, so learning about that is one of many things. There is a lot of dust on Mars, there are a lot of other things about Mars that we don't know, and the way to find out is to go there. That should be the mission objectives, that is the whole point of it, which is not a kind of thinking we have been having, and I think that is the answer to your question.

Mr. GINGREY. Gentleman, thank you for your answers.

Chairman BOEHLERT. Thank you very much, Dr. Gingrey. Ms. Jackson Lee.

Ms. JACKSON LEE. Thank you very much, Mr. Chairman. This is a vital and very important hearing, and I wish—my preference would be is that we are all sitting around in roundtables with policy-makers, Members of Congress and those of you who are experts, whether pro or con, and really seriously addressing what I think is a question of choices.

Right now before the House, we are debating $87 billion in an emergency supplemental that is larger than any supplemental we have ever had in the history of this nation. We have decided to make a choice with respect to that provision, and so, in the backdrop of this hearing, we will be debating as well as making a final decision. If I had my druthers, I would like to narrow down the question to a finite number that addresses the questions of the needs of our troops, and begin to look at the other needs of this nation. Now, frankly, I believe that there are many, many elements to this discussion about human space flight, and I add my support to Congressman Lampson's proposed legislation on space exploration.

One thing that I have noted about America is that when we face adversity, we are committed not to run and tuck our tails, if you will. We have faced adversity with the *Challenger* and *Columbia 7,* but I don't think this is the time for us to retract what I find to have a great deal of value. Let me just share some points with you. If Sir Isaac Newton had not been under an apple tree and seen the apple fall, would he have had the theory of gravity in the way that we have it? If Charles Darwin had not gone to the islands, would he have understood or at least been competitive in the question of evolution, and if scientists had not dropped—water and thrown a rock at—cannon, would we have had knowledge about botany and oceanography or physics, and so I think there are many questions.

And so I think there are many questions that we need to address, and I do want to give credence to some of the points that have been raised about whether or not we are getting the kind of return on our investment, both in human space flight as well as the Space Station, but let me lay out the atmosphere from which two very valuable astronauts are working. They are two man teams. They have to perform all of the jobs astronauts, engineers, physicians, communications specialists, and then they have to sleep, eat and exercise. It is a wonder that they have a—degree of scientific discussion. They are required to be jack of all trades, and they can not train specialists, because we have not trained specialists, research scientists might make a difference. Right now, I think the key is that we are learning to be in space and that there is value for the human space flight from that very perspective.

EDUCATION

So if I might, I would like to raise these questions for Dr. Griffin and Dr. Huntress and then I pose them to individuals who represent a different specialty. Over a period of time, what type of increase would we have to see to be responsible in human space flight? Secondarily, are we seeing a decrease in our own skill ability from students securing Ph.D.s in physics and chemistry and biology and sciences and math, and when we take the bar lower, don't give a challenge of human space flight opportunities to do research beyond science, are we decreasing the honor and the creativity that is necessary to be on the cutting edge? Frankly, if I put my science hat on, there is no way that I am going to support opposing human space flight when my good friends in China have just put a man into space. There is a certain competitive edge that I believe we cannot give up, and lastly, what is the value of understanding human capacity in space, and should we ever give that up? Dr. Griffin, Dr. Huntress?

Dr. GRIFFIN. Thank you, ma'am. Yes, it is a fact that—you have—has—enrollment in institutions of graduate learning is down. And fewer Ph.D.s are being granted than was formerly the case.

Ms. JACKSON LEE. In the sciences.

Dr. GRIFFIN. In the sciences, and certainly, I think that the collateral benefit of an enhanced human exploration program would be to help reverse that trend. I don't know if there are any other reasons for doing—for so doing, but I think it would be a collateral benefit. I think we need a competitive edge, although that is an aspect of my personality that not everyone enjoys, and I too worry about a national posture which does not want the United States to be the acknowledged leader in space exploration. Cooperation is good, but we still need to be leaders, and I think that should be our posture.

Finally, how much can we—what would be a responsible amount, I just—after—I didn't just dream of this, after considerable thought, I really felt that about a 30 percent increase from where we are, not necessarily in the present year, but allocated as the continuing amount, would allow us to gracefully exit the current road that we are on and get onto a road that we like better. Frankly, as others have said, the current budget contains enough to do new things or different things that we want to do, if—the problem is that you would have to bring to a definitive conclusion things for which we have had 20 years worth of commitments, and as an American, I dislike doing that. It is not that I endorsed those previous things. In fact, I have a very, very long record of not supporting Shuttle and Station as programs. It is just that I think we look poor in the international community if we bring them to an abrupt halt rather than terminate them gradually. Thank you.

Ms. JACKSON LEE. Huntress.

Dr. HUNTRESS. Yeah. I agree 100 percent with Dr. Griffin, but the problem is not human space flight, the problem is this kind of human space flight, and I was a Sputnik kid, you know. I grew up and I was in junior high school when all that happened. And I remember those days and what it did to inspire kids of my age, kids who normally would kind of gone past the interest in science and math. It just rekindled everything, and it created the greatest rush into colleges in the history of this country in science and math. Now, we don't have to have *Apollo* to do that again, but we have to have a program which is inspiring to our youth, and we have got what it takes, but we are not just doing it.

And so I think that a reinvigorated program with a clear understanding of the destination, what the game is and where we are going to go will bring people into the stadium. And as far as competition versus cooperation, there always has to be a balance between this. I mean the Chinese feat is—well, they should be well congratulated. They are now a part of this exclusive club, and there is a sense of competition there, and we need to lead this balance of competition versus cooperation by being a leader. That is how one does that. You lead, and that charges your competitive juices at the same time that you are cooperating and doing what we need to do.

Chairman BOEHLERT. The Chair would call on the gentleman of Missouri, Mr. Akin.

EXPLORATION

Mr. AKIN. Thank you, Mr. Chairman. You have given me the longest lunch break I have had in a week, I think. I have enjoyed that. And I have been fascinated by the discussion this morning, gentlemen. The one aspect that I haven't heard developed, and perhaps it is the most interesting, you made reference to the writings on the wall behind this concept of the vision, and I think a little bit about a couple of the people that I have done some reading on since I have been a little bit older and educated. One was Columbus, and why it was that he wanted to go around the world, and essentially, he spent years of his life trying to sell this idea, but his basic idea was he just wanted to go around the world the other way, and then you have the Lewis and Clark and their expedition, a little bit more practical about what was going on, and then just—we—not too long ago, this committee went to the South Pole, and—on the long plane ride down there, we had some time to read about Scott and Shackleton and some of the challenges of the Norwegians to the British explorers, and their different sort of attitudes toward exploration, but that just the Northwest Passage and then the South Pole, these were all things that from a practical point of view, these explorers had to come up with some sort of a logical excuse to want to do something, yet really in their heart, they just wanted to do because they wanted to it, and not so much because they had to be so practical about it, and so yet, it seems to me that there is a little bit of a pattern.

There is something in human nature that is a little kid that wants to dream and wants to go out and reach out and do something that has not been done before, and I think that is something we ought to acknowledge, that we—and I think you were, Dr. Huntress, you were talking about, you know, the Sputnik era, and that is the thing that we are looking for, is that—is a way to explain that, some way to say, look this is where we are going, and there is some logical reasons, perhaps, why some good things may come of it, but to a certain degree, we just—that is in our human nature, to explore and to reach out and to try to do things that have never been done before, and so I guess my question is, and I think that that—there is no harm in that being informed by some amount of intellect and some knowledge and some thinking, of course, but some of it is a heart thing, it is just what do you want to do, so my question to each of you would be to talk to me now like you are a 12 year old, and just I want something that is more like boy, if I could just do whatever I wanted to do, you know, look out into space and tell us, you know, what is on your hearts to do, if you had a chance to sort of—you have got the magic wand. You can design the program. Where would you like to see us going? Thank you, Mr. Chairman.

Dr. GRIFFIN. I agree with you wholeheartedly, and as my opinion a 12 year old, most of my colleagues would appreciate it if I——

Dr. HUNTRESS. Well, I think I have been a 12-year-old all my life, and that is why I am in love with space exploration, and I think you are entirely right. The reason we will go to Mars is not for scientific reasons. The reason we are going to go to Mars is for exploration reasons and for the reasons that this—that humans want to go to there, that it is in our innate nature to look over the horizon to try and discover, try and understand and better ourselves for that. And that is the reason we are really going, not for the scientific reasons. Science will benefit, but it is not going to be the primary reason.

Mr. AKIN. So, Doctor, your answer is Mars is—you think that is the next logical, good thing to sort of set on, we haven't done that yet, let us go do it.

Dr. HUNTRESS. Yeah, and if we were to put Mars and the Moon at the same distance, and say which one do I want to go to, boy, there is a slam dunk.

Mr. AKIN. Mars, right? Because we haven't been there yet.

Dr. HUNTRESS. Not only that, but it is a much more interesting planet. It is the planet in the solar system with a surface environment most like our own.

Mr. AKIN. Thank you.

Dr. KOSS. I have a great respect for the vision of my fellow 12-year-olds, and I would like to see their vision come true in some way. However, I am a condensed matter physicist, and people don't find what I do as interesting as what they do generally, but my interests, what I like, what excites people like me is looking at the inner structure and working of materials, and how they work. NASA right now has a vibrant program in physics, in combustion, in biotechnology and fluids and fundamental physics. I would just hate to see the broader vision that is described so eloquently by members of this panel injure or destroy the physical science that is going on right now and going successfully. That is perhaps——

Mr. AKIN. Is that part of the fact that we are talking about here, those different viewpoints?

Dr. KOSS. Maybe it is because right now, that program is structured with human-enabled space flight as the majority of it, and with this further discussion on where the space program can go, that program could be dropped as not being quite dramatic, though it is a tremendously successful program that could, if you removed the humans from that loop, could be done at a much greater savings and a greatly reduced risk, and I think if you keep a program like that around, it is—will also inspire you, and it will complement the larger vision that NASA goes forward with.

Mr. AKIN. Thank you.

Dr. ROLAND. Very briefly, I would just say most of the explorers you mentioned had practical purposes for going, and it is one of the concerns I have is why, for the time being, I am more focused on lower Earth orbit, because I think that is where our practical payoffs are, and also, most of them had to raise their own money. Columbus paid 11 percent of his, the cost of his own voyage. He was buying in as an investment, and it is hard to see what the payoff of these explorations are. They are very exciting, but I don't see the payoff.

Mr. AKIN. So you're saying that there is—the parallel is not quite the same here, right?

Dr. MURRAY. Getting directly to your question, rather than reconstruct my own opinions at 12, I am going to tell you about Cal Tech students, which is who, within my work, I have for decades. A surprising number really want to go to Mars, but there is nothing there for them. They are counseled to go do something else. Lower Earth orbit is a dead end, and you don't want to take a talented person in science or engineering and get them bogged down in this bogged down program.

Chairman BOEHLERT. The gentleman's time has expired.

Mr. AKIN. Thank you, Mr. Chairman.

Chairman BOEHLERT. But if you have one quick comment, Mr. Akin.

Mr. AKIN. I was just going to followup on that last answer. I don't—you say that the idea of going to Mars, that is something that the students are—did you say they are interested in it, but what did you mean when you said there is nothing there for them?

Dr. MURRAY. NASA has no program. There is no goal, there is no destination, and instead, we are bogged down in low-Earth orbit.

Mr. AKIN. So, you think that we need to hold that vision out there.

Dr. MURRAY. That is my feeling.

Mr. AKIN. And your students would get excited about it.

Dr. MURRAY. Yes.

Mr. AKIN. Thank you, Mr. Chairman.

Mr. SMITH OF TEXAS. I wonder if the question might be more challenging if it was how would you feel as a 70 year old, and you are being told that your Social Security payments are going to be dramatically cut, as well as your pension from whatever you earned, and where do you want the Federal Government to spend its money. I mean, that is the challenge that this country is facing very dramatically, and so part of what I have heard Dr. Roland and Dr. Murray is there has got to be some return on that investment. What is the practical return, and certainly, my opinion as Chairman of the Subcommittee on Research of this Science Committee is that stimulating and exciting you in math and science is part of it. I don't think Dr. Huntress, the excitement of Sputnik is still there. I mean, this program has been going since the '60s, it has lost some of its allure, it seems to me. Our challenge, now, with half of our graduate students coming in from foreign countries to do our research, that is sponsored through the National Science Foundation, should scare the hell out of us. Let me get—it seems to me that NASA—and strike the word hell, without objection, so ordered—NASA has been sort of oriented to scientific research in the past, and I think it should continue that way, and to the extent that we can justify it as far as research endeavors that result in better products or better ways to produce, more efficient ways to produce those products, then certainly, we can support that.

FREE-FLYING PLATFORMS

Dr. Koss, in terms of your suggestion for satellites or, if you will, free flyers up there, and in terms of doing some of the scientific research more effectively, more cost effectively, what would be the cost of one of these satellites, compared to a traditional satellite that we have been putting up? Is the cost of robotics and the nanotechnology and the communications system to conduct this research substantially going to increase the cost of those platforms?

Dr. KOSS. I believe that the cost of autonomous science platforms has savings over the Shuttle or Station in performing those experiments, and so by doing more autonomous and remote experiments, even in the creation of a new facility for doing so, you save money by reducing the number of Shuttle or Station resources that need to go to performing those science experiments, which will free up funds for the broader vision that NASA has.

Mr. SMITH OF TEXAS. Do you think there is a vehicle—Dr. Murray?

Dr. MURRAY. I want to comment, I am 71 years old, living on pension funds, and so I share that view strongly. I am also a deep believer in human space exploration, so I am caught, in a sense, and that seems to me to lead this painful thing I have said, we have got to restructure the existing program, and get money of that, to enable developing the vision you are talking about into something a little more real.

SPACE STATION SCIENCE

Mr. SMITH OF TEXAS. Well, it is my job, Dr. Roland, you suggested that maybe, I mean we know that the platform, the Space Station is way over budget. The prospects are that it is going to very—it could very double again. In terms of its effectiveness as a research lab, it would—should we separate the microgravity research from how humans can exist in outer space type of research, and decide where we could go there—from there in terms of manned and unmanned.

Dr. ROLAND. Right. I agree. I agree with Dr. Koss that the only—the best science on the Space Station is the human physiology science, but in my mind, we are a long way from facing the prospect of long-term manned space flight, and that is not our greatest priority, so we ought to be using the Space Station as a space platform to conduct automated experiments, and then get on with making access to space more practical.

Mr. SMITH OF TEXAS. Dr. Koss.

Dr. KOSS. The *Columbia* Accident Investigation Board concluded, or one of their conclusions is that we need to separate humans from cargo, and I would submit that many of the basic science experiments, all of the physical sciences ones and many life science ones don't involve human beings, are essentially cargo, and can be separated from the human element to great cost savings.

Mr. SMITH OF TEXAS. Dr. Griffin and Dr. Huntress, would you even agree that in terms of exploring outer space, it is more reasonable to do that with unmanned space exploration?

Dr. GRIFFIN. I think it depends on the kind of question that you are trying to answer. There, again, as Dr. Huntress and others have said, for a long time, there has been this feeling of the division between manned and unmanned space exploration, whereas in practice, it has not been that way. Pretty much when can people can automate something, they have done so, and when people are needed, people are used, for exploration, the very nature of exploration suggests that humans have to be involved, in the sense that Drs. Murray and Huntress and I have been talking, except that in our—in recent testimony, the—our administrators of NASA said that we could very easily do the shuttling with unmanned space flight. I have no problem at all, in fact, I strongly recommended that transport of crew and transport of cargo not be linked. I think that is the key to the vulnerability of the Shuttle. But that does not imply that once the cargo—humans—that——

Mr. SMITH OF TEXAS. That—and do I understand, then, that you and Dr. Huntress are—disagree with the idea that the scientific research could be done more efficiently on platforms with—more efficiently, in terms of cost and productivity of those research programs, rather than continuing the completion of the Station?

Dr. HUNTRESS. Let me try that, and I agree that most of the science which is done on Shuttle space lab flights or on the Space Station, with the singular exception of research on human physiology in space is probably more cost-effectively done on unmanned platforms or remotely operated vehicles or human-tended ones, and so I believe that the Station's good utility, if it has one, is in research on human physiology in space.

Mr. SMITH OF TEXAS. Well, and so what you feel is the long-term economic advantage to this country as far as the human's physiological reactions to outer space?

Dr. HUNTRESS. Well, the only reason that anyone would care about human physiology in space is to prepare—for humans before humans go further in space. If one is not—if one is inherently not interested in human exploration of and expansion into the solar system, then there is no reason to study human physiology in space.

Mr. SMITH OF TEXAS. And do I understand from your response that you think that that is—that that is—a policy goal that we should have, that is—whether or not it is driven by the economics of this planet?

Dr. HUNTRESS. I believe with—yes, I believe the policy goal of the United States, policy being can expand human presence into the solar system.

Mr. SMITH OF TEXAS. And for what reason?

Dr. HUNTRESS. In my earlier testimony that I truly believe in this program. What we are as humans to want to do that. I have no better reason. I acknowledge that we cannot afford to spend a lot of money on it, and I think I have pointed out that we in fact don't spend much money on it, but that it has to be done.

Mr. SMITH OF TEXAS. Gentlemen, I am going to offer my thanks and turn it back to the Chairman. Thank you.

Chairman BOEHLERT. Thank you very much, Mr. Smith. I appreciate it. I am going to wrap this up. One question I am going to ask, and I am going to ask that you give some thought to it, obviously. You have given thought to everything you have said here today, but respond in writing if you would, and this is the basic question and we will give it to you in writing. Could each of you outline with some degree of specificity what you think NASA ought to be doing and not doing over the next five years in pursuit of your vision. All right.

And then—now, this is one—hearing today, and listening to you and the exchange and the dialogue you have had with our colleagues here, I have come up with some statements, and I would like to ask each of you, you know, a quick yes or no. Do you agree with the statements and I will ask them one by one, and now, a lot of it is in the asking of the questions, and I know there are nuances, but I am trying to get a general feeling. The current NASA human flight program is not moving us toward any compelling objective—the word current is the operative word—and we should make a transition out of the Shuttle and Space Station program as soon as possible. Dr. Griffin.

Dr. GRIFFIN. Yes. I agree with it.

Chairman BOEHLERT. Dr. Huntress.

Dr. HUNTRESS. Yes.

Chairman BOEHLERT. Dr. Koss.

Dr. KOSS. Yes.

Chairman BOEHLERT. Dr. Roland.

Dr. ROLAND. Yes.

Chairman BOEHLERT. Dr. Murray.

Dr. MURRAY. Yes, yes.

Chairman BOEHLERT. Thank you. The primary reason for human exploration is the impulse to explore, rather than any more utilitarian goal that you can quantify and measure immediately, although there may be collateral benefits. Dr. Griffin.

Dr. GRIFFIN. Yes.

Chairman BOEHLERT. Dr. Huntress.

Dr. HUNTRESS. Yes.

Chairman BOEHLERT. Dr. Koss.

Dr. KOSS. Yes.

Chairman BOEHLERT. Roland.

Dr. ROLAND. Yes.

Chairman BOEHLERT. Dr.—ambitious goals without massive increases in the NASA budget. Instead, we need small increases sustained over a longer period of time. Dr. Griffin.

Dr. GRIFFIN. Yes.

Dr. HUNTRESS. Absolutely. Yes.

Dr. KOSS. Yes.

Dr. ROLAND. Yes, except I don't think we need any increase, but long-term, yes.

Dr. MURRAY. Yes.

Chairman BOEHLERT. You could see an increase for inflation, wouldn't you?

Dr. ROLAND. Yes.

Chairman BOEHLERT. Okay. We should avoid sacrificing other NASA programs to achieve our human space flight goals. Dr. Griffin.

Dr. GRIFFIN. Yes.

Chairman BOEHLERT. Dr. Huntress.

Dr. HUNTRESS. Definitely, yes.

Chairman BOEHLERT. Dr. Koss.

Dr. KOSS. Yes.

Chairman BOEHLERT. Roland.

Dr. ROLAND. Yes.

Chairman BOEHLERT. Dr. Murray.

Dr. MURRAY. Yes.

Chairman BOEHLERT. The long-term good of the human space flight program should be getting to Mars, and preferably starting colonies in space. Dr. Griffin.

Dr. GRIFFIN. Yes.

Chairman BOEHLERT. Dr. Huntress.

Dr. HUNTRESS. Yes.

Dr. KOSS. No.

Chairman BOEHLERT. Roland.

Dr. ROLAND. No.

Chairman BOEHLERT. Dr. Murray.

Dr. MURRAY. Ask for clarification what the words colonies—I don't understand what colonies in space means.

Chairman BOEHLERT. Well, outstations, like we were talking about.

Dr. MURRAY. Okay. Yes.

Chairman BOEHLERT. Yes. All right. So it is three two—on that one? All right. I want to thank you all very much, and we could keep you here all day, and it just wouldn't be fair to you. We have got a million questions. I would appreciate it if, in a timely manner, you could respond to that one specific question I asked, and I will repeat it. The long—wait a minute—identify with some degree of specificity what you think NASA ought to be doing and not doing over the next five years in pursuit of your vision of what we should have in the future of human space flight.

Now, I don't expect you to micromanage and tell us chapter and verse on how they should do everything, but I think you sense what I am asking for. Thank you so very much. I really appreciate it, and this hearing is now adjourned.

[Whereupon, at 1:21 p.m., the Committee was adjourned.]

Appendix 1:

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Michael D. Griffin, President and Chief Operating Officer, In-Q-Tel, Inc.

Questions submitted by Chairman Sherwood Boehlert

Q1. Please outline with some degree of specificity what you think NASA out to be doing—and not doing—over the next five years in pursuit of your vision.

A1. NASA should first initiate development of a heavy lift launch vehicle having a payload capacity of at least 100 metric tons to low-Earth orbit (LEO). Such a vehicle is the single most important physical asset enabling human exploration of the solar system. New manned vehicles for Earth to LEO transport, and for flight beyond LEO, are equally essential. Beyond these immediate requirements, development of nuclear propulsion systems must be re-initiated to allow efficient travel beyond cislunar space. Compact space qualified nuclear power systems are required for extended human presence on the Moon and Mars. The efficient establishment of permanent human bases do the Moon, Mars, and certain asteroids requires the use of *in situ* resources as soon as possible, to minimize the amount of material and equipment which must be brought from Earth. The technology for such exploitation has yet to be developed. Finally, space and planetary surface habitat and suit technology is at present wholly inadequate to the needs of an extended program of human space exploration.

Q2. If we are to send Americans on ambitious space missions, we are going to have to accept much higher levels of risk than those attendant in the current human space flight programs. What level of risk do you think is acceptable? How long is it likely to take to develop a program that could operate at an acceptable level of risk and how will we know what the risk level is? How can we ensure that the American people will accept a higher level of risk?

A2. Such a question calls for what can only be a personal opinion, and equally demands acknowledgement that the opinions of others may well be different. That said, I agree with the assertion that truly ambitious, exploratory space missions are dangerous almost by definition. I believe that for planning purposes we should strive for—and openly accept—a crew-loss risk of one percent, and a mission risk of five percent. This level of risk is, in my opinion, consistent with the actual level we have today in the present Space Shuttle program, and with the *Mercury, Gemini, Apollo,* and *Skylab* missions of the past. It will always be difficult, if not actually impossible, to "know" that a given level of risk has been achieved, especially if that level is low. The methods of descriptive statistics are not well suited to providing accurate assessments of risk levels when the database is as small as that which exists for human space flight at present; e.g., a few hundred "samples" at best. Analytical methods such as "probabilistic risk analysis" are somewhat more informative, but depend very strongly on underlying assumptions which are, in essence, impossible to verify. So, in the end, we can estimate risk levels but cannot know them accurately.

We can, however, know with some confidence that space exploration cannot really be "safe" in comparison with more conventional activities, and we can present this assessment clearly and honestly to the American people. In my opinion, few interested citizens would suppose otherwise, no matter what public posture was assumed. Other than via public opinion polls, we cannot "know" that the American people will accept such risks, but my own belief is that they will, provided the available information is honestly portrayed.

Q3. At the hearing, you identified the development of a heavy lift launch capability as your top priority. The context with which the question was asked was in relation to the priorities laid out by the Augustine commission in 1990. Since 1990 however, the U.S. has developed expendable vehicles capable of carrying nearly 50,000 pounds to Low-Earth Orbit. Given these developments, do you think even larger vehicles are required? If so, what are these larger vehicles needed for? If such heavy lift is required, would it be possible, or even desirable, to use the current fleet of vehicles and launch in segments to spread the risk out and to avoid the investment in an entirely new launch system?

A3. Launch vehicle payload capacity in the range of 50,000 pounds (23 metric tons) to LEO is indeed adequate for most Earth orbital missions. However, looking beyond Earth orbit to the requirements of manned lunar, asteroid, and Mars missions, substantially greater payload capacity is needed if operations are to be conducted efficiently. Even a minimal manned lunar return capability will require on the order of 50 metric tons of payload to be emplaced on a lunar transfer trajectory. A 50 metric ton translunar payload implies a roughly 100 metric ton payload in LEO, assuming a lox/hydrogen upper stage having a specific impulse of 450 seconds is used for the translunar injection maneuver. For comparison, the *Apollo* lunar missions required 40 metric tons on translunar trajectory, and provided support for two people for three days. Any future missions must reasonably be expected to improve on these parameters. Human support requirements are not easily scaled below certain minimum thresholds.

If we accept that at least 100 metric tons is required in LEO to effect a basic manned lunar return capability, it is seen that at least four launches of an EELV-class vehicle having a 23 metric ton payload capacity would be required to achieve this threshold for each lunar mission. It is my opinion that the logistical difficulties of such an operation would be impractical to the point of being essentially impossible. While EELV-class vehicles may have a role in Earth-to-LEO transportation, in my opinion they have no significant application for human missions beyond LEO.

Q4. Would a system based on the Shuttle's Solid Rocket Motors and External Tank, the so-called "Shuttle-C" concept, meet your requirement for heavy lift? Do you believe the Shuttle-C concept is the best approach to meeting heavy lift requirements? If not, what would be your recommended approach? If so, what technical issues would need to be addressed to implement the Shuttle-C concept, how much would it cost, and how long would it take?

A4. I do think it likely that Shuttle-derived vehicles, using Shuttle components such as the solid rocket boosters and external tank, could offer an expeditious approach to meeting the heavy-lift requirements for manned lunar return missions. The "Shuttle-C" concept refers to one of several such vehicle designs which have been advocated over the years, and carries the particular connotation of an unmanned side-mounted payload replacing the Shuttle Orbiter. I do not favor this particular design approach. It dogs not represent the most efficient use of the "Shuttle stack". The payload is of the order of only 80 metric tons and is not easily scaled to significantly larger values. Of equal importance is the fact that the payload fairing diameter must remain comparable to that of the present Shuttle, a significant limitation for exploration-class vehicles. More conventional "in line" Shuttle-derived vehicle configurations, notably the Marshal Space Flight Center's "Magnum" design, have also been studied, and in my opinion offer a much more reasonable alternative for meeting near-term heavy lift launch requirements.

There are no significant technical issues to impede the development of a heavy-lift Shuttle-derived vehicle. I cannot supply credible cost or schedule estimates for the recommended development, but my top-level assessment is that it could be done within two-three years for a few billion dollars at most.

Questions submitted by Representative Ralph M. Hall

Q1. A major focus of this hearing is on potential gods of the human space flight program. However, goals without adequate resources never become real programs.

Q1a. Why do you think that it has proven so difficult to get a commitment to and sustained funding for a human exploration initiative in the three decades since Apollo*?*

A1a. Apollo was initially sponsored for reasons that, even by the time it had achieved its goals, were largely moot. By 1969, the Soviet Union had effectively retired from the competition in space which had served as a symbol of clashing Cold War ideologies. By the time of the last few lunar landings, *Apollo* itself had evolved from a quasi-militaristic project into a scientifically focused exploration. But in the view of the public, the press, and our legislative and executive branches, the original motivation served to characterize the program: *Apollo* vas a race to the Moon, the U.S. had won, the other runner had fallen by the wayside, and the world had moved on to other priorities. The Vietnam War, not the Cold War, occupied American and world attention. The war's aftermath, with its accompanying "stagflation" and re-evaluation of America's place in the world, did not encourage exploratory ventures.

Had we retained the *Apollo* infrastructure—the Saturn launch vehicles, the *Apollo* command and lunar modules, and the tooling for these things—my own belief is that we would have used them again, possibly after the passage of a few years and quite likely in modified form. The lunar module was easily adaptable to an unmanned, one-way "cargo mode," which would hive allowed the steady, incremental emplacement of lunar base assets. The *Apollo* command module, modified to serve as an Earth-to-LEO transport vehicle, could have carried a half-dozen or more people and been quite substantially reusable. And it goes without saying that the world has yet to see a family of launch vehicles with the proven reliability and robustness of the Saturn family.

But the *Apollo*-era infrastructure that was developed and built at such great expense was not maintained; in fact, it was deliberately put aside in favor of the Shuttle. While the wisdom of this decision can and has been questioned, it is not necessary to do so in order to observe that the *Apollo* infrastructure, once lost, could not be easily or cheaply rebuilt. Had we retained the capability, even in a lightly "mothball" status, any Administration or Congress could have pressed for a resumption of lunar exploration, or even a Mars mission, at reasonable cost. But with the basic transportation elements gone, no Administration since Kennedy's could or would argue the "need" for sending humans beyond Earth orbit. In this assessment, they have been aided by NASA, which has for nearly three decades been unable to admit, or even to recognize, the essentially futility of developing space hardware which is inherently restricted to LEO.

Yet, it is important to note that Americans afire not against, and in fact are moderately supportive of, space exploration. Surveys have consistently shown that such support is broad but shallow; i.e., a majority of Americans favor continuing human space exploration (and robotic exploration as well, but regard it as a discretionary activity, one upon which they do not believe too much money should be spent. However, survey data also consistently shows that Americans believe the NASA civil space program to be much larger than it is; i.e., comparable to military spending in its magnitude, rather than a number which is in reality only a few percent of the Defense budget. So, more money could be spent on space exploration without violating the desires of the citizenry to maintain it in its rightful place, as the discretionary activity of a wealthy nation.

Q1b. What specifically do you think will have to The done to get such a commitment from the White House and Congress?

A1b. We need to begin with an honest public debate about the proper role of space exploration in American life, initially along the lines I have indicated above. We need knowledgeable spokesmen from the Executive and Legislative branches of government, from industry and academia, to state openly that we are where we are today based upon poor decisions made mere than three decades ago, and never corrected. We need to advocate an intelligently planned architecture, along the lines that I and others have suggested, which putt the human exploration and exploitation of the solar system, by Americans along with others, "front and center" at NASA. More money for such a program would be nice, but is not truly essential. The essential requirement is simply to agree, all together, that we have been spending the money we have on the wrong things.

I personally find it interesting to observe that the space policy decisions which have led us to our present conundrum were largely, if not entirely, made by the Nixon Administration. Subsequent Administrations have simply declined to repudiate those earlier decisions. But little else from that era receives endorsement from those in public life today; indeed, a host of governmental "reforms" were undertaken to prevent the recurrence of certain excesses from that time. Why is it that we have not questioned the space policies promulgated during the Nixon era?

Q2. The Chinese recently launched their first astronaut. They have indicated that they intend to follow up that mission with a sustained and ambitious human space flight program.

How should the United States respond to the Chinese human space flight initiative?

A2. We should regard the Chinese as serious-minded, long-term competitors for superpower status in the global community. We should recognize that the achievement and continued advancement of human space flight by China acts, and acts strongly, to enhance such status. We should realize that much of the world, perhaps most of the world, does not share our Western ideals concerning the value of personal liberty, pluralistic democratic systems, and a free and open society. We should understand that, while we are indeed very far from a perfect society, the ideals of Western thought and culture which we hold so dear cannot endure, and certainly cannot prevail, unless America can lead the way. In future centuries, it will be seen, and seen to be obvious, that leadership of the human expansion into space is, by itself, the single factor guaranteeing pre-eminence in human society to the Nation or nations possessing it. Despite our setbacks, Americans today still leads the world in its mastery of space flight. This leadership was largely purchased with a sustained investment during the 1960s, an investment approaching four percent of the Federal budget in some years. It should be recognized that the Chinese intended to wrest this leadership away from the United States; the only uncertainty in their vision concerns the time scale. Do we really wish to allow this to occur?

Q3. The most recent U.S. human space flight program—the International Space Station—involves a partnership of 15 nations.

Q3a. Should international cooperation be an intrinsic part of any future human space flight initiative, or do you think that a future initiative would be better managed as a U.S.-only undertaking?

A3a. I discussed in my written testimony the fact that the United States today spends a trivial portion of its wealth on space flight—an amount equivalent to less than 15 cents per person per day. Increasing this amount by about 30 percent together with re-orienting today's program would, in my view, provide the proper basis for a sustained program of human space exploration. But, as I have noted above, even today's $15 B annual funding for NASA is sufficient to accomplish much of what is needed, if programmatic priorities could be properly redefined. So, as a "bottom line," and in a strictly technical sense, it is clear that the United States does not "need" international partners to accomplish any goal in space.

But I have argued, here and elsewhere, that space policy is among other things an extension of foreign policy, and in the long run is *the most significant* aspect of that policy. To a large extent, leadership in space in the twenty-first century and beyond will convey the same benefits to the Nation possessing it as did mastery of the air in the twentieth century, or mastery of the seas in the eighteenth and nineteenth centuries. So the United States must lead. But leaders must have followers, and even more importantly, they must have allies and partners.

The United States *can* act unilaterally to achieve any desired goal in space, and can achieve it before any competitor can hope to do so. But we *should* set out to achieve such goals in company with those who share the vision and the ideals which shape our society.

It should be noted that America's record as a leader in multilateral space enterprises is mixed, at best. We have much work ahead of us to demonstrate the reliability and constancy of purpose that partners are entitled to expect in such an effort.

Q3b. What are the pros and cons of international cooperation on future human space flight projects?

A3b. An international project will, almost inevitably, take longer and be accompanied by a substantial degree of frustration as the parties attempt to overcome political, cultural, linguistic and fiscal barriers to effective cooperation.

Questions submitted by Representative Bart Gordon

Q1. The Hubble *Space Telescope, like the* Chandra *and* SIRTF *space-based observatories, could have been designed to work without the capability to be serviced by humans. Is servicing scientific spacecraft an appropriate task for humans in space? Is it an appropriate risk for humans in space to accept?*

A1. With specific regard to the Great Observatories, including *Hubble, Chandra,* and *SIRTF,* my own answer must be that servicing these platforms is worth the risk of life. Lives are risked, and sometimes lost, in any large construction project. Lives were lost in the building of the famous Mt. Wilson Observatory. But from that observatory, Edwin Hubble measured and later explained the galactic redshift that has led to our present understanding of the universe. The Great Observatories have allowed, and will allow, us to make new and equally fundamental observations. And, while it may be possible in theory to build such complex machines so well that they need no human interaction, I personally do not know how to do it, nor do I know anyone who can claim with any confidence to know how to do it.

More generally, the risk of space flight is not a reason for humans to abstain from space missions, it is a reason for us to strive to learn how to do our jobs better. Almost by definition, there is always risk to be found on a frontier, and space is today's frontier.

Q2. In what ways, if any, would a base on the Moon contribute to our ability to send humans to Mars?

A2. On Mars, we will need surface suits, habitats, rovers, power sources, and a host of other tools, technologies, and processes that we do not have today. To test them for the first time on Mars, many months from home, with our last experience beyond LEO having occurred in December 1972, seems to me to be very foolish indeed. It is certainly true that some things needed for the first missions to Mars will not have a useful lunar analog. But, wherever possible, we should test on the Moon those things we will need to do to survive for weeks or months on Mars.

Q3. As of three years ago, development of a low-cost, highly reliable reusable launch capability to low-Earth orbit was viewed as a central goal of the human space flight program that would enable a wide range of new options. In the last year or so, NASA seems to have decreased the priority of that goal. How high an investment priority do you think that goal should be for NASA?

A3. As I have indicated in other forums, including prior testimony to this committee, I regard the pursuit of low-cost, reliable, reusable space launch capability to LEO to be a central goal of the Nation's civil space program. In this era, after more than four decades of space flight, far more progress toward this goal should have been made than has been observed. More effective space transportation is the enabling technology needed by the United States if it truly desires to master space flight.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Wesley T. Huntress, Jr., Director, Geophysical Laboratory, Carnegie Institution of Washington

Questions submitted by Chairman Sherwood Boehlert

Q1. Please outline with some degree of specificity what you think NASA ought to be doing—and not doing—over the next five years in pursuit of your vision.

A1. In the next five years NASA needs to make progress in the hardest problem; a less costly, lower risk system for access to low-Earth orbit by crew and separately by cargo. Devise the simplest and safest systems separately for crew and cargo transport to low-Earth orbit.

Q2. If we are to send Americans on ambitious space missions, we are going to have to accept much higher levels of risk than those attendant in the current human space flight programs. What level of risk do you think is acceptable? How long is it likely to take to develop a program that could operate at an acceptable level of risk and how will we know what the risk level is? How can we ensure that the American people will accept a higher level of risk?

A2. Higher risk will be acceptable if the public perceives that our astronauts are exploring, not acting as plumbers and electricians trying to keep the ISS afloat. Risk is hard to measure, but it is easy to perceive. We know that capsule return systems riding on top, not on the side, of launch vehicles are safer than the Shuttle design. We proved it before Shuttle and the Russians have demonstrated it since 1961. Go back to it. You don't need wings and joysticks in space; only on X-planes.

Questions submitted by Representative Ralph M. Hall

Q1. A major focus of this hearing is on potential goals for the human space flight program. However, goals without adequate resources never become real programs.

Q1a. Why do you think that it has proven so difficult to get a commitment to and sustained funding for a human exploration initiative in the three decades since Apollo*?*

A1a. It has been difficult to get a commitment for a human exploration initiative because the U.S. government has lost its long-term view of the health of the Nation. Bogged down in near-term issues, mainly war-fighting, in the past 30 years the Nation has turned introspective and xenophobic. Industry, commerce and government have become throttled by the Wall Street mentality—all effort focused on the next quarter rather than some effort invested on the long-term future. The Administration and Congress no longer look beyond the next election. There are no statesmen and leaders.

Q1b. What specifically do you think will have to be done to get such a commitment from the White House and Congress?

A1b. To get a commitment the public has to demand it. And this won't happen until our astronauts actually do something in space; they've done nothing in 30 years while the robotic program has dazzled everyone. Or unless the public perceives that others are passing us while we wring our hands.

Q2. The Chinese recently launched their first astronaut. They have indicated that they intend to follow up that mission with a sustained and ambitious human space flight program.

How should the United States respond to the Chinese human space flight initiative?

A2. We should respond to the Chinese by welcoming them to the club, dropping our stand-off attitude, establish strong cooperation in space with them and inviting them to join in the International Space Station.

Q3. The most recent U.S. human space flight program—the International Space Station—involves a partnership of 15 nations.

Q3a. Should international cooperation be an intrinsic part of any future human space flight initiative, or do you think that a future initiative would be better managed as a U.S.-only undertaking?

A3a. Future exploration, especially beyond Earth orbit, should be a global enterprise of cooperating nations. I think the U.S. should be the instigator and the leader, but not insist as it has in the past to be solely in control.

Q3b. What are the pros and cons of international cooperation on future human space flight projects?

A3b. The pro of international cooperation is that it will bring the nations of the world together in a multi-cultural, engaging enterprise. The con of international cooperation is that it will be harder to manage, take longer and will cost more. Its well worth it.

Q4. You mentioned in your testimony that "Exploration is not what motivated Kennedy to open the public purse, beating the Russians dad." What is a comparable motivation for our time and place?

A4. Kennedy's motivation was nationalistic and covertly military. There is no comparable motivation today. Instead it should be international and peaceful cooperation—a method not to demonstration national power and will, but to demonstration international magnanimity and good will.

Question submitted by Representative Bart Gordon

Q1. The Hubble *Space Telescope, like the* Chandra *and* SIRTF *space-based observatories, could have been designed to work without the capability to be serviced by humans. Is servicing scientific spacecraft an appropriate task for humans in space? Is it an appropriate risk for humans in space to accept?*

A1. Space telescopes will soon reach a size that cannot be launched on a single rocket and will require in-space assembly. Their complexity will mean higher cost, so that servicing an expensive facility is more cost efficient than reproducing it. This kind of construction and servicing of delicate instrumentation is best done by humans, as demonstration by Hubble servicing. The spectacular results from these space telescopes most certainly justify a certain amount of risk for astronauts; it has been among the most valuable work that Shuttle astronauts have done.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Matthew B. Koss, Assistant Professor of Physics, College of the Holy Cross

Questions submitted by Chairman Sherwood Boehlert

Q1. Please outline with some degree of specificity what you think NASA ought to be doing—and not doing—over the next five years in pursuit of your vision.

A1.

Introduction

In *Imagined Worlds,* physicist Freeman Dyson ruminates about the non-destined future determined and informed by science and technology. Dyson introduces his eloquent set of essays with two remembrances of things past.

Dyson remembers his wife's uncle Bruno, a country doctor in a big house in a small village. Uncle Bruno inherited his house and his practice from his father and expected to do likewise with his offspring. Dyson recalls,

> When I admired the large oak tree that stood in front of the house, Onkel Bruno said in a matter-of-fact tone, "That tree will have to come down; it has passed its prime." So far as I could see, the tree was in good health and showed no signs of imminent collapse. I asked him how he could dare to chop it down. He replied, "For the sake of the grand children. That tree would last my time, but it would not last theirs. I will plant a tree that they will enjoy when they are as old as I am now." He expected his grandchildren to inherit his practice and live their lives in his home. That is the way it was in the world that he knew.. . .Horizons are long, and it is normal and natural to look ahead a hundred years, the time an oak tree takes to grow.

Dyson also recalls that when he was a student, his college also identified long-term issues that required immediate decisions and actions as an investment in the future. Here he says,

> The driveway to Trinity on the river side came through a magnificent avenue of elms planted in the eighteenth century. The elms were still beautiful but past their prime. The college decided, like Onkel Bruno, to sacrifice the present for the sake of the future. The avenue was chopped down and replaced by two rows of scrawny saplings. Now, fifty years later, the saplings are growing toward maturity. The avenue is again beautiful, and it will grow to full height as the twenty-first century goes by. Trinity College has been a great center of learning since it was founded in the sixteenth century, and it intends to remain a great center of learning in the twenty-first.

So when I am asked to identify what NASA should be doing over the next five years in pursuit of a vision of the future of human space flight, I take Dyson's parables to heart.

The single most important task NASA needs to address in the next five years to realize a future for human space flight is to *formulate and begin to enact a vision for next 100 years.*

Importance of Vision

Prior to even the Wright Brothers and Kitty Hawk, we had the dreams of space flight from the science fiction visions of Jules Verne and H.G. Wells. Such dreamers and visionaries did more then just entertain. They inspired. It is said that the space age began on March 16, 1926 in Auburn Massachusetts (about one mile on the other side of Pakachoag Hill from my office at Holy Cross) with Worcester native Robert H. Goddard's instauration of the "Space Age" by launching the first liquid fueled rocket 184 feet over what was then his "Aunt Effie's Farm," and what is now the Pakachoag golf course.

As a boy, Goddard read Verne and Wells, and inspired by their fiction, became the physicist who launched the space age. However, unlike other early and equally inspired rocket scientists, such as Konstantin Tsiolkovsky and Hermann Oberth, Goddard combined Tsiolkovsky and Oberth's book learning of rocket dynamics with American know how to actually design, build and operate a working rocket.

Throughout the years the artistic visions of Chesley Bonestell as published in *Life* helped a nation envision human space flight, while the fiction of Arthur C. Clarke, Robert Heinlein, Issac Asimov, among others, and television shows like Star Trek, continue to entertain, inspire, admonish, provide expression, and encourage thinking about the future. More recently and after the fact of the *Apollo* Moon landing, physicist Gerald O'Neill combined more hard science and a little less science fiction in imagining and advocating for giant rotating artificial gravity generating hollow cylindrical space colonies at the Earth-Moon *L5* and other Lagrangian points. O'Neill's intellectual progeny and current source of utopian views and space advocacy are embodied in organizations like The Mars Society and The Space Frontier Foundation.

Such visionaries and those inspired by them form a vast human capital sustaining tremendous faith in technologically imagined futures, and in the generation of grand visions and ideas, some of which may be novel and useful. The next H.G. Wells and Robert Goddard may come from these ranks and those inspired by them. We need their vision, their energy, and their evangelical zeal to form and sustain a long-term vision. However, the long term vision NASA needs to weave in order to conduct near term activities must be somewhat less ambitious, less contentious, and more rooted in proven or near-term technologies and practicalities. The Space Studies Board (SSB) of the National Research Council (NRC), The Planetary Society (TPS), the International Academy of Astronautics (lAA), to name but a few, embody this type of bold, clear, imaginative, and yet pragmatic and realistic thinking.

Constraints On The Vision

A recent Zogby International poll indicated that a vast majority of Americans are in favor of human space flight despite the assumptions of inherent risks. At the same time, a Houston Chronicle Poll indicated that a majority believes that the Shuttle program should be held in abeyance until a vision of the future of human space flight has been promulgated. Clearly the public is still dedicated to a human future in space, but desire clarity of purpose and a detailed articulation of that purpose. Lastly, the public appears to stand ready to participate in and support the necessary change in space policy to realize that purpose.

The chief task for NASA in the next five years is to lead the Nation in forming a long-term consensus vision for the agency regarding our future in space, and begin the programmatic changes to towards that realization.

However we must be mindful that no matter how compelling or exciting the vision or how large a majority support it, there are scientific, engineering, and economic realities that need to be reckoned. We can't vote on the truth.

Chairman Boehlert, in his opening statement for the October 16th hearing on the future of human space flight succinctly and properly identified five constraints within with a vision needs to be formed. Based on Boehlert's statement we have the following constraints:

1. There must be a consensus arrived at jointly by NASA, the White House, the Congress.
2. Human space flight is not the only NASA responsibility, or, even maybe the most important of its responsibilities.
3. There must be an agreement to pay for the agreed upon vision even though and in consideration that NASA will not have an unlimited budget.
4. We need to be open and honest about the purposes and challenges of human space flight.
5. We must be cognizant and informed from the mistakes we've made over the past 30 years.

Possible Visions

NASA's overall mission to improve life here, to extend life there, and to find life beyond, as only NASA can, is proper and correct. The challenge occurs in the details when that overall broad mission has to be focused down to actual programs. It is then that the vision becomes blurry, and thus we now need to refocus and refine that vision.

The key reports mentioned in the Charter of the October 16th hearing on the Future of Human Space Flight, from the 1984 Paine Report to this year's CAM report, have much to tell us about what our vision needs to include, how to accomplish that vision, and what to be wary about. Furthermore, using and modifying the recommendations of these reports is consistent with the imperative to incorporate the lessons learned from the last 30 years of human space flight. However, in addition to the reports listed in the hearing charter, we should add the post-Sputnik I *Introduction to Outer Space* prepared by a committee lead by James R. Killian, Jr., and the Wiesner report released just months prior to Yuri Gagarin's first human-in-space orbital flight. Both reports advocated for the primacy of unmanned spacecraft in the exploration of the solar system and beyond.

Although both of these early reports largely advocated for NASA to lead a scientific exploration of space with a limited role for human space flight, it was decided then that the symbolic and geopolitical need to demonstrate technical superiority and virtuosity over the Soviets then trumped the scientific visions of the Killian and Wiesner reports. Now however, that particular goal was completed when *Apollo 11* returned safely to Earth in July of 1969. We had then demonstrated to the world our technical virtuosity. We had won that battle. It is now time, over 30 years later, to return to many of the ideas of those earlier visions that better balanced resources and goals for both remote/autonomous and human tended missions.

In addition to not being a rocket scientist, I am not a visionary. I was invited to the hearing on the *Future of Human Space Flight* and asked to prepare this written response for the record because I saw something that was wrong with the status quo, forthrightly called it out, and asked NASA to change it. Nevertheless, although I cannot formulate a vision, I can recognize the merit in the visions of others. In fact, the other panelists at the October 16th hearing, by their very statements, enunciated and identified a common ground for the future of human space flight.

There was general agreement, solicited by the concluding questions form the chair, that: the human impulse to explore is the chief reason to do so although there may be collateral benefits, we can take on ambitious goals for the future of human space flight with reasonably small and consistent budgets, we need to avoid sacrificing other NASA programs to do this, and we most definitely need to make a transition from the current Shuttle and Station programs. There may even be a consensus that the long-term goal is the colonization of Mars, provided that that destination is the product of a larger public consensus and envisioned in a reasonable timeframe.

In detail, I think that Dr. Huntress, based on his work with the IAA, best expresses the common vision in terms of actionable goals and thoughtful observations:

1. The goal of establishing a permanent human presence in the solar system with the stated objective to establish human presence on Mars by the middle of this Century.
2. Recognition that exploration beyond Earth orbit is intrinsically global, and should involve cooperation with other space-faring nations.
3. A progressive, step-by-step approach for human exploration beyond Earth orbit that does not require an *Apollo*-like spending curve. Any requirements for increased spending can then be made incrementally on an annual basis.
4. A set of exciting and rewarding destinations in this step-by-step approach to Mars including the Sun-Earth Lagrangian Point L2, the Moon and Near-Earth Asteroids.
5. Re-invention of our Earth-to-orbit transportation and on-orbit infrastructure to support the goals for exploration beyond Earth orbit. The current Space Shuttle and International Space Station are not on that critical path other than research on human physiology in space.
6. Development of new in-space systems for transporting humans and cargo from low-Earth orbit to deep space destinations. No large technological breakthroughs are necessary.
7. Continued use of robotic missions for scientific research and preparation for future human flights. Robotic precursor missions will be required to reduce the risk for human explorers and to provide on-site support for humans. Human explorers will be required for intensive field exploration and for in-space servicing of complex systems.

What to Do, Now!

It was clearly pointed out by Dr. Roland that the Space Shuttle has been our most dangerous and deadly vehicle. The CAM report clearly recommends that we separate humans from cargo. Thus it seems inescapable that we need to start a robust and continuing program to design, build and operate new Earth-to-orbit transportation systems for humans and cargo. The success of any long term goal or vision will require routine and reliable access to low-Earth orbit (LEO). When and if the requirements and needs for human exploration beyond Earth orbit are agreed upon, understood, and begun, an infrastructure to reach LEO will stand ready and able.

To develop a simpler, safer and less costly system for transporting humans and cargo to and from LEO we need to deal with the current Space Shuttle and International Space Station Programs. The Shuttle should be retired after flying only those missions necessary to complete a suitably modified and scaled back International Space Station. The goals of the ISS should be refocused to those specific purposes required to support NASA's suitably chosen long term vision, and the ISS itself should be modified appropriately to those goals and the program held in abeyance until those goals are formed and articulated.

To be sure, the U.S. has obligations to its international partners to continue to work with them, but there is absolutely no obligation to complete a pre-Columbia International Space Station plan since it has been determined that that plan is in need of modification. Good and fair partners will recognize that changes are necessary, and they will be anxious to work with the U.S. to help form the new long-term vision, and to participate with us on its implementation.

All this must be done while maintaining and balancing the needs of other NASA programs. NASA is bigger and more important than any single program. NASA was formed from several existing agencies, including the National Advisory Committee of Aeronautics (NACA). So while NASA must certainly lead in the human exploration and development of space, it must continue to lead in the development and aeronautics and science where NASA has a unique and special role. The programs that involve human space flight must be scaled back. We can no longer afford for the human space flight programs, despite their romance and appeal, to dominate or diminish other NASA programs.

Lastly, these immediate actions and plans need to be woven into the developing, long-term, and consensus vision of what NASA should do. NASA needs to immediately, forthrightly, and openly, get on with the business of discussing, debating, and deciding what should be done.

Additional Issues and Comments

In order to best achieve both any immediate and long-term goals, we must to heed the constants listed above. Let me illustrate this with the discussion of some additional issues.

No goal, either long-term or in the here and now, should require an *Apollo*-like, or any other crash program. There is no overarching security, technological, or symbolic need to accomplish anything quickly that would require such a crash program. We are charged to learn from the past, and indeed we must. However learning from the past does not mean we should try to relive the successes of the past. The *Apollo* program was unique and successful, but did not lay the foundation for what comes next. Let's celebrate and remember the *Apollo* program for what is was, but at the same time, let's move on. At this time, a crash program for its own sake is lunacy.

We must have sufficient change in NASA in both its vision and its conduct. The CAM report made this clear. However this change is beyond just the fixing and tinkering with current programs. No single program or pallet of programs will do. As Drs. Murray and Griffith made clear, we need a new way of thinking about the future of NASA and the future of human space flight. We need to think of it as a new "way of life." No step or program should be a terminal one where once completed we declare success without knowing what to do next. Rather every step or program should be part of a new forward looking "way of life" where the completion of one step or one program leads to the next. No mere footprints, flag, and celebration will do.

As we are required to learn from our mistakes, we must also endeavor to learn from our successes and from our history too. The voyage of Columbus or the expedition of Lewis and Clark come to mind as oft cited examples. However, we must be careful to not be too selective in taking the lessons from the past, from mythology, or from deftly made catch phrases or high sounding rhetoric. These stories of the past carry many meanings, and we should attempt to see in them both similarities and differences to our current situation, as well as inspiration and warning.

For example, to be sure the development of the West depends on Columbus' voyages. However his arrival in the new world owed a great deal to luck, financial backing with an eye to profits, some exaggerated claims for the chance of success, and in addition to its benefits wreaked havoc and death to the indigenous population. To propel his ships across the ocean Columbus did not need to take a source of energy with him, but had the warm power of the wind, and when he found land, it was a rich and nurturing one. Lastly, even with these advantages, continuous European settlements in the "new world" did not commence for well over 100 years after the "new world's" discovery to Europe.

In addition, the "undaunted courage" of Lewis and Clark was aided and abetted by the knowledge and courage of native guides. Yes indeed, Lewis and Clark did not take with them most of what they needed for sustenance, but the land they explored turned out to be perhaps the richest of lands. So we may take a lesson from the Lewis and Clark Expedition about the prospects for future colonies on Mars as opposed to the Moon, or a Lagrangian point, but we should not see in Lewis and Clark's success or the Nation's return on investment, an analogous reason for a manifest destiny in space.

As another example, John F. Kennedy's phrase "this new ocean" captured the romance and human capacity and drive for exploration, but the comparison to that old ocean are not always so apt. Likewise, Heinlein's phrase, "halfway to anywhere" as a description of LEO, or the shores of "this new ocean" is correct in terms of energy accounting, but not so in terms of time or risk. The time to go anywhere beyond LEO are orders of magnitude greater than the minutes required to reach LEO. The greatest risk to reach and return to LEO are chiefly those of safely obtaining and dissipated enough energy, while the risk of being in orbit are in bringing to orbit enough food, water, air, and energy to sustain life and counteract the effects of apparent weightlessness. To go beyond LEO increases the risk of these requirements, and adds to them the considerable risks of radiation beyond the safety of the Van Allen Belts. Thus the shores of "this new ocean" beckon, but are not such that we can easily wade in, and the idea of "halfway to anywhere" is only halfway true, if that much.

I mention these examples not to advocate for any position but that of careful and logical thought and analysis in the charting of a course for the future. History and catch phrases can and should inspire us, but they do not and should not direct us to any particular course or vision. Rather they indicate to us how we should evaluate and pursue a chosen course or vision.

In addition, we need to continuously remind ourselves that the vision is not the goal. The goal is to set a 100-year vision. The 100-year vision is needed to organize, direct and sustain our current and near future activities. We must be wary that we don't substitute the vision for the goal so that the vision becomes fossilized and incapable of change. As the saying goes, "prediction is difficult, especially about the future." The further out we go, the less accurate and useful our initial vision will become. We must be able to change and modify the vision as we encounter a future that we have planned for but that hold some surprises as well.

This is not to say that our vision should be so malleable or amorphous that it can be easily changed or abandoned. No, the truth is far from that. The vision must be constructed to resist change while at the same time be open to the right type of change for the right type of reasons. The change can only come from knowledgeable, weighty and involved sources that have respect for the vision they wish to modify, and base the modifications and the need for modification in the "teeth or irreducible and stubborn facts." We need our 100-year vision to be like a good scientific theory. That is, although resistant to changes and the direction in which the wind blows, our vision needs to be flexible enough to grow and undergo minor modification, and if after a full life, it eventually dies, it dies gracefully, and leaves a descendant rather then a wholly new vision.

There has been some discussion about the role of technology versus the role of mission in delineating what NASA does or attempts to do. NASA Administrator Sean O'Keefe has said that NASA should develop technologies and then determine where to go while critics argue that without concrete goals, technological investments will be unfocused, inefficient and vulnerable. Both positions are essentially correct and can be usefully combined. We need a concrete long-term vision so as to direct and sustain technological development programs, but we need already developed technology to determine where to go and what missions to perform in the short term. There should be no dichotomy between the two views what comes first, technology or mission.

This issue and the issue of flexibility and the modification of long-term visions as well as that of the benefit of crash programs are combined in the issue of technological breakthroughs. Technological breakthroughs, even if strived for and seeded for with generous funded, cannot be predicted. Burton Richter beautifully discusses this in his September 1995 *Physics Today* article, *The Role of Science in Our Society,* where he points out that "the road from scientific discovery to new technology is a wayward one." Thus, unless there is no reasonable alternative, crash programs are inefficient, ill advised and generally only successful when there is short term definitive goal that is a final step and not a first step, i.e., like the *Apollo* program or the Manhattan project. This is inconsistent with the "new way of life" that is recommended for the future of human space flight.

Nevertheless, though unpredictable, the results and benefits of technological breakthroughs can be managed and incorporated if done the right way. Take the example of the revolutionary changes brought from the invention (based or detailed and well supported basic research) of the point contact transistor. Robert Park in his book *Voodoo Science: The Road From Foolishness to Fraud* relates a story about a vision of science fiction author, engineer, and futurist Arthur B. Clarke with regards to the development communication satellites and transistor-based microelectronics. Park says,

> Arthur C. Clarke, who is probably best known as the author of *2001: A Space Odyssey,* predicted in a 1945 article in *Wireless World* that artificial satellites

in geosynchronous orbits would one day be used to relay radio messages around the world. A satellite in a geosynchronous orbit, which is at an altitude of about twenty-three thousand miles, has an orbital period of exactly twenty-four hours, just matching the rotation of the Earth. To an observer on Earth, the satellite thus appears to remain stationary. Communications experts scoffed; in 1945 the idea of an "artificial moon" was still science fiction. It would be another twelve years before the Soviets would shock the world with the launch of Sputnik I.

It was a brilliant insight. Today, there are nearly two hundred communications satellites; it's a $15 billion per year business and still growing, but it's doubtful that communications satellites as envisioned by Clarke would have been practical. His satellites were manned space stations, with living quarters for a crew whose principal task was to replace vacuum tubes as they burned out. Arthur C. Clarke foresaw communications satellites, but he did not foresee microelectronics—no one did. Just two years after he described his dream of space stations, the transistor was invented, and soon after, the integrated circuit. No larger than Volkswagens, each of today's communications satellites flawlessly relays millions of times as much information as the huge manned space stations Clarke proposed, and today's satellites have no need for a crew.

Science is a wild card. The further we try to project ourselves into the future, the more certain it becomes that some unforeseen, perhaps unforeseeable advance in science or technology will shuffle the deck before we get there. Often, as in the case of semiconductor electronics, science provides us with a future far beyond our dreams; other times it reveals unexpected limits. Science has a way of getting us to the future without consulting the futurists and visionaries.

The historian Arnold Toynbee once explained his phenomenal productivity: "I learn each day what I need to know to do tomorrow's work." Science advances in much the same way. With each hard-won insight, the scientist pauses just long enough to plot a new course, designed to take advantage of what has just been learned. Before some distant goal can be realized, new discoveries may render it less desirable or reveal a more attractive alternate. Science keeps offering new futures to choose from and crossing old ones off the list.

There is a wonderful irony here that I'm using Park's words to defend a vision for the future of human space flight and the benefits of physical science research on orbit. Park is perhaps the most ardent, articulate and harsh critic of NASA's human space flight and on-orbit laboratory science programs. However, if science and the history of science teach us anything, it is to judge a person's arguments and not their autobiography. In the story Park relates above, and with respect to the use of humans in space, he has both good facts and a cogent argument that commands our attention, respect, and perhaps even some concurrence. In the case of Park's criticism of laboratory physical science contained elsewhere in his book and his public statements, I find his logic correct but based on wrong data and false "facts." Thus his argument there fails to hold. So even Park himself, in a way, is defending the key objectives of basic research on-orbit. And who knows, maybe a technological breakthrough from science in LEO will have consequences for the human exploration and development of space even though its principal objectives are geared to improve life here.

Summary/Conclusions

To repeat, and in conclusion, what should NASA do over the next five years? They should:

- Form the focused, long-term, consensus vision.
- Change institutional culture per the CAIB report.
- Start perfecting access to LEO.
- Learn from the successes and errors of the past.
- Plan to phase out the Space Shuttle in accordance with a modified and scaled back plan for the ISS.
- Maintain and modify the good work of NASA's overall mission including basic research on orbit.

Q2. At the hearing, you did not concur that the long-term goal of the human space flight program should be going to Mars. Please explain why you do not think this is the right goal to pursue. What do you think the long-term goal should be?

A2. Although personally I think that the long-term goal of NASA's human space flight program should be going to Mars, I feel more strongly that the long-term goal should be fully supported by the Nation. If the Nation as a whole feels, based on an informed discussion of the costs and benefits, that human space flight should be curtailed, I would support that decision. If the decision where to go to Mars, in the proper way cognizant of the constraints discussed above, I would more happily support that decision.

In references to my research as part of NASA's physical science in space program, I feel that if the general public is not convinced by the full weight of the arguments in it favor of the importance of science on orbit so as to fund it, then so be it. The Nation's refusal to support science would be honest, and we would need to accept it until we can change the perception or the opinion via better or more education on the matter. I feel likewise with the goal of Mars as part of the human space flight program. The long-term goal is to have and support the consensus.

Q3. If we are to send Americans on ambitious space missions, we are going to have to accept much higher levels of risk than those attendant in the current human space flight programs. What level of risk do you think is acceptable? How long is it likely to take to develop a program that could operate at an acceptable level of risk and how will we know what the risk level is? How can we ensure that the American people will accept a higher level of risk?

A3. The decision to accept risk, and how much risk to accept, can only be made by those who assume the risk. As a patient with Multiple Myeloma, I face risk analysis decisions frequently. Prior to any risky medical procedure, I am briefed fully on the risks and the benefits of a procedure. At the conclusion of the briefing, I am required to sign a consent form indicating both my understanding of and consent to the procedure, despite the associated risks. I have accepted procedures with specified mortality rates as high as two percent to five percent. I did so knowingly, and based on an informed assessment that being young and otherwise healthy, my risk was probably less then two percent, and that the risk of not doing the procedure is far greater in the long run. This does not remove the responsibilities of my attending medical care providers. They must commit themselves to take due diligence and to attempt to minimize risk whenever possible. The formal signing procedure merely indicates that all parties are fully informed as to the risks and benefits of the procedure and our responsibilities to each other. However, in all cases, the decision to assume the risk, no matter how much it affects my wife and daughter, remain my own. This is as it should be.

In the human space flight program, the astronauts understand the risks involved in their work, and accept them willingly. Perhaps the astronauts who fly make Faustian bargains and accept grave risks in exchange for an experience they value greatly, or for the benefit derived professionally, or for the contributions, both symbolic and concrete, to humankind, or perhaps for all these reasons. For whatever the reasons, the decision to assume the risk needs to be theirs and theirs alone.

Our responsibility as a nation, NASA as the agency in charge, and mine as a scientist, is to do due diligence to both minimize the risk for the task that is being undertaken, and to ensure that the risk is fully understood and not underestimated by those who assume the risk. Lastly, we need to be scrupulously honest about the true goals and rewards for which that risk is being taken. Similarly, I think that the American people will allow astronauts to accept a higher level of risk provided that the details of the goals, risks, and the consent to assume the risks are all publicly discussed and acknowledged by all parties. This does not specify what the particular risk-taking goal is or should be, but only that the goal itself is acknowledged fully.

Questions submitted by Representative Ralph M. Hall

Q1. A major focus of this hearing is on potential goals for the human space flight program. However, goals without adequate resources never become real programs.

Q1a. Why do you think that it has proven so difficult to get a commitment to and sustained funding for a human exploration initiative in the three decades since Apollo*?*

A1a. Representative Hall is correct in saying that goals without adequate resources never become real programs, and that is certainly part of the explanation for why three decades after *Apollo* there is no sustained funding for human space flight. The very first post-*Apollo* program, the Space Shuttle Program (SSP), started the trend where we committed ourselves to the program we could afford. Thus, there was no clarity of purpose or vision since a program decision was made for completely economic considerations and not scientific or technological ones. Furthermore, the funds and efforts required to meet the overly optimistic plans and promises of an overly compromised SSP, and later the ISS, starved other and better NASA programs and plans. Lastly, the *Apollo* program, although a great success, is not the model for future successes.

Q1b. What specifically do you think will have to be done to get such a commitment from the White House and Congress?

A1b. The House Committee on Science has already begun a process to get a commitment to and sustained funding for a human space flight from the White House and Congress. The committee is asking the right questions, and is getting the right answers. I have no idea how one gets the necessary commitment for the rest of Congress and the White House, but hope that an honest and open discussion, with honest disagreements, continues to part of the process. I greatly appreciate my opportunity to participate in this process, and hope I am able to continue to do so.

Q2. The Chinese recently launched their first astronaut. They have indicated that they intend to follow up that mission with a sustained and ambitious human space flight program.

How should the United States respond to the Chinese human space flight initiative?

A2. We have, as we should, already welcomed the Chinese to the club of human space-faring nations. Beyond that, I neither know of or can think of any technological, symbolic, or security issues that require that we repeat history to better the Chinese at any of their articulated goals. At this time, we should and can vigorously pursue our vision for NASA's future without reference to what the Chinese space program. If, at any time in the future, this analysis needs to change, we can do so. At this time, we have a detailed history behind us, and some issues and challenges ahead for which we are engaged.

Q3. The most recent U.S. human space flight program-the International Space Station involves a partnership of 15 nations.

Q3a. Should international cooperation be an intrinsic part of any future human space flight initiative, or do you think that a future initiative would be better managed as a U.S.-only undertaking?

Q3b. What are the pros and cons of international cooperation on future human space flight projects?

A3a,3b. I have heard said that perhaps the best thing about the International Space Station is the word international. In fact, the current grounding of the Space Shuttle fleet is only possible since the ISS can be supported by Russian launches. Thus, international cooperation should continue to be a part of our nation's future in human space flight. For the future of human space flight, this lowers our costs, makes available the best in international science and technology, and contributes to good international relations. The only con to this is that the decision making process on certain elements may be more unwieldy since there is no single decision making authority.

Question submitted by Representative Bart Gordon

Q1. The Hubble *Space Telescope, like the* Chandra *and* SIRTF *space-based observatories, could have been designed to work without the capability to be serviced by humans. Is servicing scientific spacecraft an appropriate task for humans in space? Is it an appropriate risk for humans in space to accept?*

A1. The human servicing of scientific spacecraft is not appropriate if the spacecraft could have been designed to work autonomously or remotely. It would only be appropriate for humans to service scientific spacecraft provided it has been affirmatively demonstrated that human tending is the only reasonable way for a platform to be operated and that the benefits yielded from that platform are deemed to be worth the risks. Or alternatively, there is goal or an acceptable decision for humans to be in space, whatever it is, and it is determined that while they are there achieving that goal, they might as well service the spacecraft. As stated previously, the appropriateness of the risk depends on the full acknowledgments and acceptance by all parties of the nature of the risk and the goal requiring that risk.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Alex Roland, Professor of History, Duke University

Questions submitted by Chairman Sherwood Boehlert

Q1. Please outline with some degree of specificity what you think NASA ought to be doing—and not doing—over the next five years in pursuit of your vision.

A1. Over the next five years, NASA should concentrate on launch vehicle development. The Space Shuttle is the weak link in the United States space program. It renders the Space Station untenable. The United States should retire the Space Shuttle or fly it unmanned. If manned flights are deemed essential before the availability of a replacement, human-rated launch vehicle, the Shuttle should be used sparingly and with minimum crews. If it does fly with people aboard, all extent anomalies that threaten crew safety should be resolved to the satisfaction of an *external* panel of experts, not one appointed by NASA.

The nature of the launch vehicle development program should be driven by a national consensus on what the country wants to do in space. If returning to human space flight is a priority, then the first development should be a space plane to ferry astronauts to and from low-Earth orbit. But I see no compelling urgency in returning American astronauts to space. So launch vehicle development might better focus on lowering the cost of access to space. If one or more new launch technologies can be developed to increase the efficiency and reliability of placing payloads in orbit, then all space activity, manned and unmanned, will eventually benefit.

During this period of launch vehicle development, NASA should exploit its current capabilities in automated space flight. This year's missions to Mars are good examples of unmanned missions with the potential to capture the public imagination. More arresting still would be the mission that has been possible for years but never funded: an automated, roving, return mission. This spacecraft would fly to Mars, land softly, dispatch a roving vehicle to explore the planet under remote control from Earth, return to the lander, and fly aboard it back to Earth. The country that first returns to Earth with a Martian soil sample will secure its reputation as the world's leader in space exploration.

Q2. At the hearing, you did not concur that the long-term goal of the human space flight program should be going to Mars. Please explain why you do not think this is the right goal to pursue. What do you think the long-term goal should be?

A2. There are two compelling reasons for not going to Mars in any foreseeable future. First, we do not have the technology to do this safely and economically. In the absence of a new launch vehicle, we would have to rely on the Shuttle for this undertaking. The Shuttle has demonstrated that it is not equal to the task. Estimates for a manned Mars mission have reached $400 billion. I do not know of any space mission that has ever come in under cost. More recent estimates that a quick-and-dirty mission can be completed for $60 billion or even $30 billion should be treated with the same credibility that we now attach to projections for an $8 billion space station.

Even if the Nation were prepared to spend $400 billion on a manned Mars mission, we would still want to know why. What purpose would be served by such an adventure? Scientific exploration can be done more thoroughly, more reliably, and more cheaply with automated spacecraft. Is there some economic payoff to be derived from flying men to Mars and back? I don't know what it is. Are we proposing to colonize Mars? What for? What purpose would a colony serve? Whose colony would it be? As signatories to the Space Treaty, we have forsworn claims on extraterrestrial bodies. At a time when the world community is divided on whether and how to sustain a manned presence at the South Pole, it is hard to imagine how we would justify the staggering expense, to say nothing of the risk, of sustaining a human presence on Mars. If we are going to Mars, as we went to the Moon, just to prove we can do it, just to complete a feel-good mission, then what will we do when we come home? For thirty years now we have been unable to find a compelling reason to send humans back to the Moon. There will be still less reason to send men back to Mars. Then we will be where we are now, having flown a historic but ultimately empty mission, the completion of which leaves us with the same nagging question: What next? Proposals to send humans to Mars, such as those by Bruce Murray and the Planetary Society, envision the mission as an end in itself, just as the *Apollo* missions were. They will not lead to anything useful. They will be followed by calls for sending humans to one of the Martian moons or one of the

Lagrangian points or some other place in our solar system, not because there is anything for people to do there but just because it makes some people feel good. Let those who will feel good pay for it.

Q3. At the hearing, you identified the development of launch capability as your top priority. The context with which the question was asked was in relation to the priorities laid out by the Augustine Commission in 1990. Since 1990 however, the U.S. has developed expendable vehicles capable of carrying nearly 50,000 pounds to Low-Earth Orbit. Given these developments, do you think even larger vehicles are required? If so, what are these larger vehicles needed for? If such heavy lift is required, would it be possible, or even desirable, to launch in segments to spread the risk out and to avoid the investment. in an entirely new launch system?

A3. My recommendations for launch vehicle development are not so much for lifting capacity as for economy. Only one space activity has ever paid for itself satellite communications. All other space activity is too expensive to be conducted by the private sector. Government subsidies are required to support space science, weather satellites, even the quasi-commercial imaging of Earth from space. Manufacturing and tourism have never approached commercial viability. Even the armed services maintained that space-based missile defense, should the country ever attempt it, would require an order of magnitude decrease in launch costs. Space science is insulated from normal peer-reviewed competition for research funds because the payoff from even the best of missions could seldom justify their cost in competition with the most compelling Earth-based proposals. For all the wonderful achievements of space science, its costs would embarrass most scientists. For most of the last thirty years NASA has spent almost as much on space science as the National Science Foundation spends on all other scientific research save medical and nuclear. There is no question which investment has provided the highest returns.

NASA said when it first began to develop the Shuttle that for a space station and other such ambitious undertakings in space to be practical, launch costs had to be reduced by an order of magnitude, the same goal identified by the Department of Defense. The Shuttle did not decrease launch costs; it increased them. Incremental refinements of expendable launch vehicles over the last two decades have improved efficiency, but we still operate on a plateau that may perhaps represent the upper limits of chemical rockets. NASA should either push chemical technology beyond that plateau or turn to other launch technologies. Many proposals have been advanced. Few have received more than meager support. Unless there is a dramatic reduction in costs to low-Earth orbit, then America's and the world's future in space will be practically limited to what we have seen for the last forty-five years: one commercial success in Earth orbit; many important military programs conducted at enormous costs; and a large number of state supported space activities conducted *pro bono publico.* More ambitious activities, such as human exploration and habitation, commercialization, mining, tourism, and other potential realms of human space activity will remain impractical. No segment of our space program is more important than reducing launch costs and increasing reliability.

It should be noted that this economic reality could be transformed by large-scale demand for space activity. If, for example, the economics of energy generation on Earth ever deteriorated to the point where large solar collectors in Earth orbit became feasible, then the demand for energy could support the construction of huge, orbital infrastructure, probably in geosynchronous orbit. Once that infrastructure was paid for by the consumer, additional activities in space would have to pay only the marginal costs of moving beyond the infrastructure. In other words, a large transportation system carrying payload and personnel to solar collectors in geosynchronous orbit could readily add tourists and planetary travelers for acceptable marginal costs. But it is hard to see that happening within the next twenty-five years, or even fifty years. And even if it did, the enterprise would be vastly more affordable and practical if it could draw upon new launch technology. Indeed, new launch technology might speed the day when cheap, clean energy from space could be delivered to Earth to substitute for dwindling supplies of fossil fuels.

Q4. If we are to send Americans on ambitious space missions, we are going to have to accept much higher levels of risk than those attendant in the current human space flight programs. What level of risk do you think is acceptable? How long is it likely to take to develop a program that could operate at an acceptable level of risk and how will we know what the risk level is? How can we ensure that the American people will accept a higher level of risk?

A4. I believe that America's tolerance for risk in the space program is comparable to our tolerance for casualties in war. It is a myth that we are casualty-intolerant in war. Many recent studies have confirmed that Americans are willing to accept risk if they believe the casualties are necessary to ensure our nation's security. Americans will similarly accept risk to astronauts if they believe the resulting casualties serve vital national interests. The skepticism being heard in the wake of the *Columbia* accident suggests that Americans are not as convinced as they once were that flying astronauts in low-Earth orbit has been worth the loss of life. The polite fiction that our astronauts have been conducting essential scientific experiments or that they are the essential trailblazers of some far-reaching program of exploration and expansion has been belied by the sorry record of manned space flight since *Apollo.* Truth be told, astronauts such as those aboard the ill-fated *Columbia* have been carrying out the same tired agenda repeated endlessly over the last three decades: fly into low-Earth orbit, float around in near weightlessness, smile for the upbeat television interview, exercise relentlessly to retard the deleterious effects of weightlessness, and return to Earth to spend most of your working life talking to tourists in Florida or Houston or making public appearances at high school career fairs. The public is hard pressed to identify anything going on that is worth the risk.

The public might be willing to tolerate more risk in a human mission to Mars. But most Americans have given little thought to the prospect of accident or illness aboard a spacecraft beyond rescue or succor from Earth. In the last two years we have seen dramatic rescue missions of scientists who fell ill at the South Pole. These were more difficult and dangerous than most of us would have expected. Imagine the ordeal of watching an astronaut or an entire crew succumb to misadventure or disease while the world looks on helplessly. There will surely be questions of whether the light was worth the candle. I, personally, feel no obligation to protect astronauts from risks that they undertake voluntarily, but recent experience suggests that the astronauts have not always known the dangers to which they were being subjected. So it is not just their bravery and willingness that are at issue, but rather the national trauma when we support an ill-advised undertaking that runs afoul of the law of averages.

Questions submitted by Representative Ralph M. Hall

Q1. A major focus of this hearing is on potential goals for the human space flight program. However, goals without adequate resources never become real programs.

Q1a. Why do you think that it has proven so difficult to get a commitment to and sustained funding for a human exploration initiative in the three decades since Apollo*?*

A1a. There are at least five reasons why the country has not supported a human exploration initiative since *Apollo.* First it, is too expensive. Anything that we want to do in space with our current launch technology costs ten times as much if humans participate. No one, to my knowledge, has completed a cost-benefit study demonstrating that the value added by humans in situ begins to compensate for the added cost of sending them.

Second, if the goal is exploration, automated spacecraft can do it far more safely, reliably, and efficiently that humans. The notion that humans have to be physically present for exploration to take place is an anachronism that weighs down the space program and hinders development of a rational, feasible, and imaginative program of space exploration.

Third, human space flight to date has proved to be a feel-good program with little demonstrable payoff. We got our money's worth out of *Apollo,* because the payoff was psychological, a competition for the hearts and minds of the world's people in the depths of a frightening Cold War. Since then only a vocal minority of Americans have cared much about human space flight one way or the other; most are simply indifferent.

Fourth, they are indifferent because it has proved to be boring. Nothing is happening in our manned space flight program. The public takes an interest only when there are celebrities on board or there is a disaster. We are doing what we did thirty years ago. To most Americans, going to Mars sounds too much like going to the Moon; an expensive stunt leading to another dead end.

And fifth, the American public appears to have greatly diminished faith in NASA. When someone as mainstream as Bryant Gumbell calls NASA the gang that can't shoot straight, then one can be sure that the agency's reputation has sunk from its *Apollo* highs to the lowest levels of American cynicism about bureaucratic government programs that suck up tax dollars and deliver little in return. The most reliable feature of NASA's performance in the last thirty years is that its programs are always late, over cost, and under specifications. There is little wonder that public and Congressional support for ambitious new human initiatives in space is limited to the true believers who have a spiritual commitment to human space flight that transcends the harsh reality of NASA's record.

Q1b. What specifically do you think will have to be done to get such a commitment from the White House and Congress?

A1b. I doubt that Congress or the White House will back a major new human initiative in space until we have safe, reliable, and economical access to low-Earth orbit. A fair bench mark will be an order-of-magnitude reduction in launch costs and 99 percent reliability for any human-rated launch vehicle. And the launch costs and reliability will have to be certified by a competent, independent oversight body, such as the National Academy of Sciences. NASA claims about safety and economy have lost all credibility. If this benchmark is achieved, then an enormous range of opportunities will open up in space. These will include space commercialization, so that space activity begins to pay for itself instead of always depending on government subsidy. And it would also include practical human space flight.

Q2. The Chinese recently launched their first astronaut. They have indicated that they intend to follow up that mission with a sustained and ambitious human space flight program.

How should the United States respond to the Chinese human space flight initiative?

A2. The Chinese are now doing what we did forty years ago. Their program poses neither threat nor challenge to the United States. We should wish them well. Indeed, I believe that we should seriously consider trying to sell them the Space Station. It is a white elephant that they might want for prestige and we cannot support because of the fatal weaknesses of the Shuttle. If we offered the Space Station for sale, we could give our Station partners first refusal to buy us out. If they declined, we could offer the Chinese the opportunity to take our place. In either case, we could then offer the new owners access to the Shuttle at cost, if they wished to accept the risk of flying it until they or we have developed a next-generation, human-rated launch vehicle. In fact, the U.S. might want to retain a ten percent share of the Station in the interests of international cooperation. We could afford that, and we could use the income from the sale to speed up development of our next-generation launch vehicles.

Q3. The most recent U.S. human space flight program—the International Space Station—involves a partnership of 15 nations.

Q3a. Should international cooperation be an intrinsic part of any future human space flight initiative, or do you think that a future initiative would be better managed as a U.S.-only undertaking?

A3a. Internationalization of space activity is a sound principle. It promotes cooperation. It spreads the financial burden. And it comports with our commitment in the Space Treaty not to make any national claims on space or its resources. The Space Station, however, provides an unfortunate example of how not to conduct an international space project. Our international partners make only token contributions, and they receive access out of proportion to their shares. Furthermore, when something goes wrong, as in the crisis precipitated by the *Columbia* accident, they exert political pressure to sustain a program that continues to suit their purposes but no longer suits ours. We have made ourselves hostage to our international partners without achieving any benefit commensurate with the mortgage that they hold on our future plans.

Q3b. What are the pros and cons of international cooperation on future human space flight projects?

A3b. The U.S. disposes about one third of the world's wealth. In multi-national space projects we should seek to ensure that all participants contribute proportionally to their national wealth and resources and that they benefit proportionally to their investment. If we want to allow a developing nation to participate at a lower level, then we should treat that as a foreign-aid issue, not a space policy issue. If we are using space projects as instruments of foreign policy, then the goals and costs should be laid out explicitly, and exit strategies for all parties should be negotiated in advance. Developing a complex, large-scale technological system is difficult in the best of circumstances. Doing it with international partners complicates the enterprise in ways that make no technical sense, just political sense. We should nonetheless embrace those complications, for the political payoff is substantial. But all of the costs and benefits for all of the parties should be articulated and calculated in advance.

Question submitted by Representative Bart Gordon

Q1. The Hubble *Space Telescope, like the* Chandra *and* SIRTF *space-based observatories, could have been designed to work without the capability to be serviced by humans. Is servicing scientific spacecraft an appropriate task for humans in space? Is it an appropriate risk for humans in space to accept?*

A1. Given the current limitations on our launch capacity, we should not use humans to service any space-based observatories. As was true with *Columbia,* none of the science being conducted is worth the risk of human life. What is more, servicing space-based observatories by humans actually raises the cost of the enterprise and limits the science that can be done with the available funding. Take the Space Telescope, the best known of the space-based observatories. It was designed to be launched on the Shuttle and serviced by Shuttle astronauts. Without that limitation, it could have been a more powerful and more versatile instrument. It need not have been limited to the size and weight limitations of the Shuttle. More importantly, it could have been placed in a higher orbit, where it would have been able to do more and better observations. And it could have been launched more cheaply on an expendable launch vehicle than on the Shuttle. What is more, several space telescopes could have been built and launched on expendable launch vehicles for the cost of launching, repairing, and servicing the Hubble. The cost of service and repair is so high with manned Shuttle flights, that it is actually cheaper to build and launch a second spacecraft than it is to visit and restore an existing one. And the second spacecraft can be an improved model, based on the experience with the first. The military has been operating its many and varied spacecraft this way for decades. The military is not known for cost-control, but its enormously complex space program is nonetheless proof that human-servicing in orbit, even of very expensive spacecraft, is simply not necessary. The servicing of space-based observatories by NASA has been driven less by economy, safety, and efficiency than by the imperative to give the Shuttle something to do and to create a public impression that the Shuttle is useful. If we ever develop truly safe, reliable, and economical access to the whole range of Earth orbits, from low to geosynchronous, it may prove practical to send people to service orbiting spacecraft. In the meantime, we are far better off with autonomous free flyers monitored and controlled from Earth.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Bruce Murray, Professor of Planetary Science and Geology Emeritus, California Institute of Technology

These questions were submitted to the witness, but were not responded to by the time of publication.

Questions submitted by Chairman Sherwood Boehlert

Q1. Please outline with some degree of specificity what you think NASA ought to be doing—and not doing—over the next five years in pursuit of your vision.

Q2. At the hearing, you stated that the "issue of on-orbit assembly needs to be understood," and that it "may change the launch vehicle requirements significantly." Can you please explain what needs to be done to understand on-orbit assembly operations and how this may change the launch requirements. What recommendations do you have to improve the U.S. capability to perform autonomous operations on-orbit?

Q3. If we are to send Americans on ambitious space missions, we are going to have to accept much higher levels of risk than those attendant in the current human space flight programs. What level of risk do you think is acceptable? How long is it likely to take to develop a program that could operate at an acceptable level of risk and how will we know what the risk level is? How can we ensure that the American people will accept a higher level of risk?

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Q1. A major focus of this hearing is on potential goals for the human space flight program. However, goals without adequate resources never become real programs.

Why do you think that it has proven so difficult to get a commitment to and sustained funding for a human exploration initiative in the three decades since Apollo*?*

What specifically do you think will have to be done to get such a commitment from the White House and Congress?

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Q3. The most recent U.S. human space flight program—the International Space Station—involves a partnership of 15 nations.

Should international cooperation be an intrinsic part of any future human space flight initiative, or do you think that a future initiative would be better managed as a U.S.-only undertaking?

What are the pros and cons of international cooperation on future human space flight projects?

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Q1. The Hubble *Space Telescope, like the* Chandra *and* SIRTF *space-based observatories, could have been designed to work without the capability to be serviced by humans. Is servicing scientific spacecraft an appropriate task for humans in space? Is it an appropriate risk for humans in space to accept?*

Q2. The Jet Propulsion Laboratory is perhaps the world's most advanced planetary research organization.

What do you think can be learned about life on Mars using a purely robotic approach?

At what point, if any, does a human presence on Mars become essential for further scientific advancement of our understanding of Mars?

Appendix 2:

Additional Material for the Record

STEPPING INTO THE FUTURE

A Workshop in Memory of the Columbia 7

On April 29–30, 2003, The Planetary Society, the Association of Space Explorers, and the American Astronautical Society held a workshop at the George Washington University's Space Policy Institute about the future of human space transportation. The following conclusions have been endorsed by The Planetary Society and the American Astronautical Society and by a number of astronauts present at the workshop. ASE did not take a formal position on the conclusions.

Conclusions

Human space exploration is a great and unifying enterprise of planet Earth. The loss of *Columbia* reminds us that astronauts are the emissaries of humankind as part of our civilization's aspirations for great achievements and new discoveries. The United States' commitment to human exploration reflects humankind's movement outward from Earth, to become eventually a multi-planet species. We do this to understand and cope with the limits of Earth, its finite resources and indeed its finite lifetime, and to satisfy the innate desire of people to advance civilization and understand their place in the universe. We do this not just for our own country, but also for all our planet's citizens. Furthermore, the space enterprise provides a unique means of building national intellectual, technical and personal capabilities. It is a commitment to a positive future.

The Planetary Society, the Association of Space Explorers–USA, and the American Astronautical Society convened a group of experts at a workshop, in memory of the *Columbia* Space Shuttle crew, to assess launch vehicle requirements to meet the needs of human space exploration beyond Earth orbit. Our conclusions from this assessment are:

The Imperative

- There are strong societal imperatives for exploring space. The natural curiosity to explore new frontiers coupled with an instinctive desire to preserve the future of humankind motivates our continued exploration of space. Space exploration will provide new knowledge and resources for a more prosperous and secure future.
- There are fundamental questions concerning our cosmic origin, our future and whether or not we are alone in the Universe. Science in pursuit of these questions can provide a credible goal-oriented strategy for an evolutionary approach to exploring deep space destinations with both robots and humans.
- The exploration of deep space by humans will be energized by the goals of individual nations woven into an international enterprise and infused with a sense of human destiny in space.

The Destinations

- The most important scientific destinations for human explorers are the Moon, Mars, Near-Earth Objects and the Sun-Earth Lagrangian point L2[1] (for astronomical observatories).
- Mars is the ultimate destination for human explorers in the foreseeable future. Consequently the robotic Mars exploration program should progress beyond sample return to robotic outposts in preparation for human presence.

A Strategy

- By adopting a phased approach to human exploration beyond Earth orbit, we can develop a cost-effective program that is exciting, scientifically rewarding and for which the risks can be measured and managed.
- The initial stages of a robust human exploration architecture can proceed using existing and currently planned propulsion technologies.
- We see no essential role for continuing flight of the Shuttle orbiter beyond its immediate goal of completing construction of the International Space Station and early transport of crew members to and from the Station. As soon as an alternate mode of human transport into and from low-Earth orbit

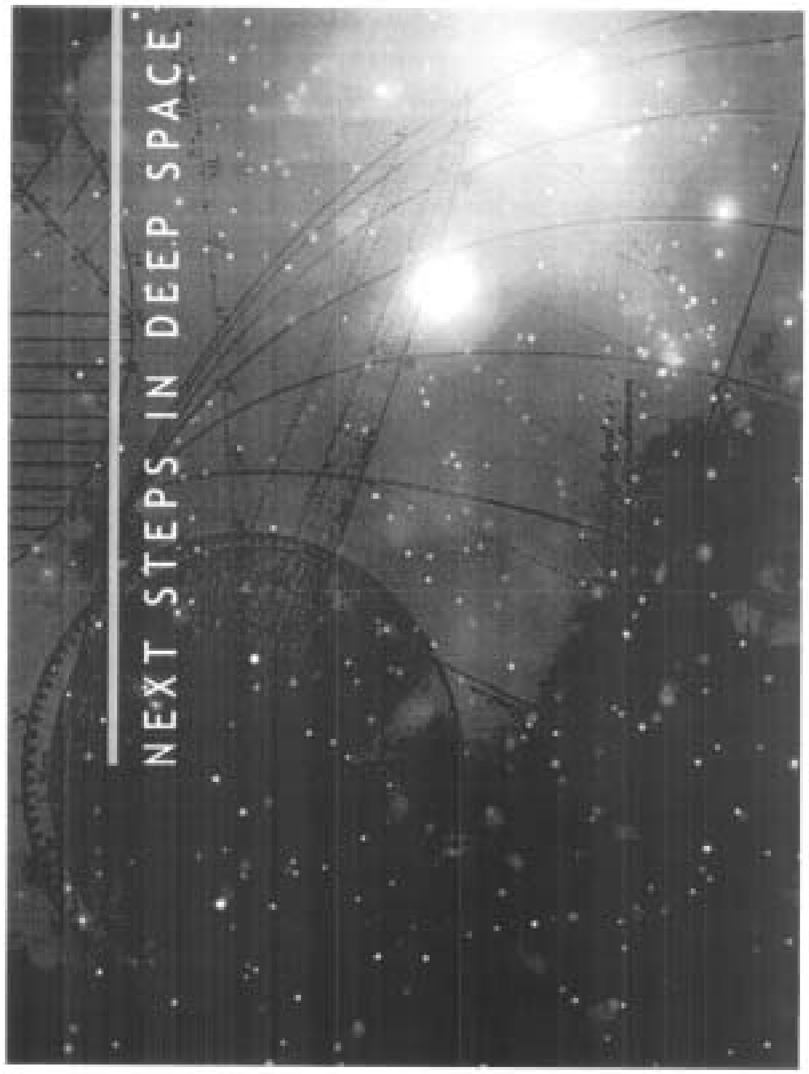
[1] Lagrangian points (L1–L5) are points in space where the gravitational forces from the two most nearby influential gravitational masses (in this case the Sun and Earth) are in equilibrium.

(LEO) is available, which should be accomplished as soon as possible, the Shuttle orbiter should be retired.

- Crew and cargo should be transported separately to increase flexibility, reduce cost and reduce risk associated with human space exploration.
- The under-utilized fleet of existing expendable launch vehicles should play a major role in the next stages of human space exploration, as well as in human and cargo transportation into LEO.
- Increased investment in on-orbit operations and in-space propulsion technologies is required.

International Cooperation

- Exploration beyond Earth orbit is an intrinsically global enterprise. It is unlikely that any nation acting alone will commit the necessary resources for a major human exploration mission initiative beyond Earth orbit.
- International partnerships provide tangible benefits for human space exploration. These include broadening public and political support, sharing of the cost and risk, adding resiliency and enriching the scientific and technological content.
- To this end all space faring nations should strengthen mechanisms for exchanging information on human exploration activities and plans, increase international participation in robotic exploration missions, and explore mechanisms for sharing critical roles among partners.


NEXT STEPS IN DEEP SPACE

Next Steps in Exploring Deep Space

A Cosmic Study by the International Academy of Astronautics

- A vision for the future and a description of what *could* be done
- Not a strategic plan or a product of any national space agency
- Human space exploration as a global enterprise

A logical and systematic roadmap

- To establish a permanent human presence in space
- For conducting scientific exploration of the solar system and the Universe
- With a goal to land humans on Mars sometime in the next 50 years
- Evolutionary architecture emphasizing intermediate destinations of scientific and programmatic value: *Stepping stones to Mars*

A work in progress

- Final report to be submitted in early 2004
- All ideas and contributions are welcomed

NEXT STEPS IN DEEP SPACE

IAA

IAA NEXT STEPS IN DEEP SPACE

The Imperatives: Why Explore Deep Space?

To Discover - the exploration imperative

- Expand the frontiers of human experience
- Fulfill the basic human need to always move forward
- Inspire, educate, and engage our youth and the public

To Understand - the scientific imperative

- Knowledge and understanding of what surrounds us in space
- Answers to fundamental questions of our origins and destiny
- Advance and sustain human learning and technological progress

To Unify - the political imperative

- Toward a global endeavor without national boundaries
- Toward mutual achievement and security through challenging enterprise
- Toward human utilization of the solar system

IAA NEXT STEPS IN DEEP SPACE

Ages-old human questions lead to scientific challenges

Where do we come from?

- Determine how the universe of stars and planets began and evolved
- Determine the origin and evolution of Earth and its biosphere

What will happen to us in the future?

- Determine the nature of the space environment and cosmic hazards to Earth
- Determine the potential for human permanent presence in space

Are we alone in the universe?

- Determine if there is or ever has been other life in the Solar System
- Determine if there are life-bearing planets around other stars

How do we meet these challenges?

- Conduct a systematic, scientific exploration of the Solar System
- Conduct astronomical observations of the Universe beyond

NEXT STEPS IN DEEP SPACE

IAA

From Science Objectives to Exploration Objectives

Science objectives lead to the following exploration objectives...

- Conduct astronomical investigations using large space observatories
- Conduct scientific exploration of the Moon, Mars and (later) Europa
- Conduct a scientific survey of a diverse suite of Near Earth Objects

...at four destinations which can be reached by humans in the next 50 years

- Sun-Earth Libration Point L2, the Moon, NEO's, and Mars

...which can lead to a permanent human presence in space

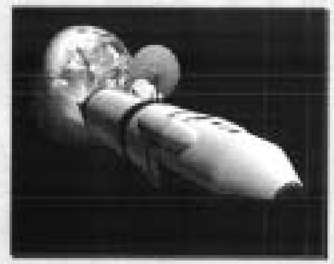
- Robotic exploration leads to a human outpost at L2
- Capabilities grow to encompass visits to NEO's and the Moon
- Human exploration of Mars can be achieved by the middle of this century

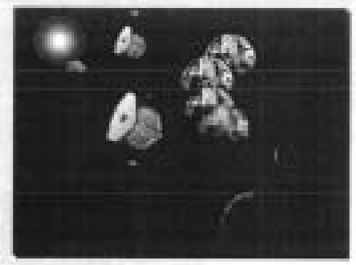
IAA NEXT STEPS IN DEEP SPACE

Destination: Sun-Earth L2

A constellation of space telescopes

- Survey the Universe across the spectrum and to the beginning of time
- Observe the process of planetary system formation in the galaxy
- Search for terrestrial-like planets around other stars
- Search for evidence of life in the spectrum of extra-solar planets





Exploration architecture

- Initial step: A "Deep Space Shuttle" providing access from LEO
- Human outpost for assembly and maintenance of observatories
- Preparation for later interplanetary voyages
- Trade study: Humans at L2 vs. other locations (with robotic transfer of telescopes)

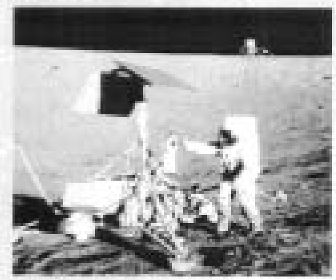
NEXT STEPS IN DEEP SPACE

IAA

Destination: Moon

Lunar outposts for exploration on the Moon

- Search for evidence of the origin of the Earth-Moon system
- Determine the history of asteroid and comet impacts on Earth
- Obtain evidence of the Sun's history and its effects on Earth through time
- Search for samples from the earliest episodes in the history of the Earth
- Determine the form, amount, and origin of lunar ice



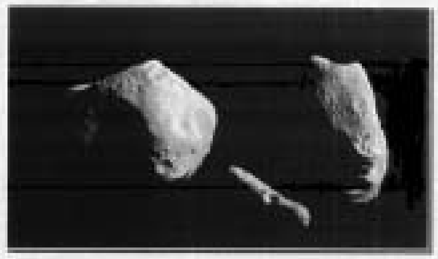
Exploration architecture

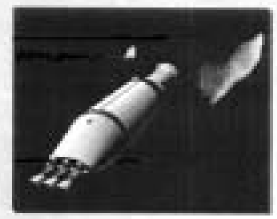
- A proving ground for development of surface systems, habitats, and technologies
- Deep Space Shuttle provides the necessary transportation capability
- Possible use of lunar resources to enhance access to other destinations
- The Moon may not be in the "critical path" to Mars

Destination: Near-Earth Objects

Field exploration of asteroids

- Survey the diversity and composition of NEO's
- Determine the bulk properties and internal structures of NEO's
- Determine utility of NEO's as potential resources for materials in space and how we might mitigate future Earth impacts





Exploration architecture

- An intermediate deep space destination to test a human Mars expedition
- Cargo (via SEP) and crew travel separately from L2 or other gateway, to minimize crew flight time
- High degree of commonality with L2 infrastructure

IAA NEXT STEPS IN DEEP SPACE

Destination: Mars

Outposts on Mars - robots and humans working together

- Determine the geological and climatological histories of the Mars
- Determine the history of water and its distribution and form on Mars
- Search for evidence of past and current life on Mars
- Establish a permanent human presence on Mars - the most Earth-like planet

Exploration architecture

- Cargo travels separately via SEP or NEP, crew rendezvous at or near Mars
- All exploration equipment and habitats arrive before crew for risk reduction
- Phobos/Deimos a possible first destination in Martian system to reduce incremental investment; high commonality with NEO infrastructure

NEXT STEPS IN DEEP SPACE

IAA

Guiding Principles of the Architecture

Mars is the goal

- Intermediate destinations and local architectures are established with this ultimate goal in mind

Science-driven

- Address key questions of broad scientific and public interest
- Science goals and objectives provide context for destinations, capabilities, and technology investments

Stepping-stone approach

- Logical progression to successively more difficult destinations
- Minimize incremental investments to maintain progress; adjust destinations if necessary to help manage cost and risk

Utilize existing or planned capabilities

- Avoid requiring major new technology developments early in the program
- Solar electric and nuclear electric propulsion, along with improved chemical propulsion, can meet early transportation needs

Separate cargo and crew

- Minimize crew flight time by using minimum-mass transfer vehicles
- Cargo, supplies, and exploration equipment travel in advance of crew using highly efficient electric propulsion