
# Issues and Opportunities Regarding the U.S. Space Program: A Summary Report of a Workshop on National Space Policy

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ISBN: 0-309-53010-5, 92 pages, 8 1/2 x 11, (2004)

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# Issues and Opportunities Regarding the U.S. Space Program

## A Summary Report of a Workshop on National Space Policy

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**Space Studies Board**
**Aeronautics and Space Engineering Board**
**Division on Engineering and Physical Sciences**
NATIONAL RESEARCH COUNCIL
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NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

This study was supported by Contract NASW-01001 between the National Academy of Sciences and the National Aeronautics and Space Administration. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the agency that provided support for the project.

International Standard Book Number: 0-309-09146-2 (book)
International Standard Book Number: 0-309-53010-5 (PDF)

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Space Studies Board
National Research Council
500 Fifth Street, N.W.
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# Preface

The NASA Authorization Act of 1958 (and its amendments) set very broad objectives for the U.S. civil space program. They include, inter alia, expansion of human knowledge of the Earth and space, development and operation of space vehicles, and preservation of U.S. leadership in aeronautical and space science and technology. In May 1961, President Kennedy set the nation on an explicit course of human exploration when he proposed "achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to the earth." Kennedy's decision was very much influenced by desires to surpass the Soviet Union in space achievements. Following the Apollo program the roles and direction of human spaceflight often have been controversial and uncertain. Many blue-ribbon panels have addressed the issue, sometimes from the limited perspective of what should be the nation's goals in human spaceflight and on other occasions from a broader perspective that examined the space program in its entirety. The aftermath of the shuttle *Columbia* tragedy in February 2003 initiated a growing public debate over the purpose and future of the U.S. civil space program.

At its 141st meeting, the Space Studies Board (SSB), in collaboration with the Aeronautics and Space Engineering Board (ASEB), organized a workshop for the purpose of contributing their collective experience and expertise to this debate, as well as to encourage a continuing broad national discussion about the future direction of the U.S. civil space program. The workshop took place November 12 and 13, 2003, at the Arnold and Mabel Beckman Center of the National Academies in Irvine, California. Including the participating members of the SSB and ASEB, a total of 55 invitees engaged in a series of five panel discussions and open general discussions over the course of the day-and-a-half event. The workshop agenda is included in Appendix A of this report, and a list of the participants and invited guests is included in Appendix B.

The workshop was intended to explore aspects of the broad question, What should be the principal purposes, goals, and priorities of the U.S. civil space program? (The complete statement of task is provided in Appendix C.) The goal of the workshop was not to develop definitive answers but to air a range of views and perspectives that will serve to inform later broad public and political discussion of such questions. Therefore this report represents a factual summary, prepared by the rapporteur, Radford Byerly, with staff assistance, of the proceedings of the workshop, including summaries of individual presentations. It should not be taken as a consensus report of the SSB or ASEB or of the National Research Council.

The charge for the workshop included broad questions about the principal purposes, goals, and priorities of the U.S. civil space program. All speakers and participants were encouraged to consider the questions in their written abstracts and oral remarks. In addition, the opening of each chapter outlines specific questions the speakers were to address in the workshop sessions, including issues about the contributions of science and exploration, the economic contributions of space, space and foreign policy, and interactions among national security, military, and civilian space efforts. SSB Chair Lennard Fisk, in his opening remarks, also referred to the broad questions and multiple factors that can contribute to raising the level of debate on what the nation should be doing in space, and he outlined the objectives of each session. It was in this spirit of the breadth of issues influencing the space program that the workshop was held.

In the end, rather less discussion time was devoted to the space and Earth science programs than to the human spaceflight program, largely because the participants saw the latter as being more problematic and less robust than the former. Participants observed attributes of the science programs that were missing in the human exploration program and saw the opportunity to apply lessons learned from the comparison for the improvement of the human spaceflight program.

This report is organized according to the following approach: Chapter 1 provides a brief overall



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summary of cross-cutting themes and issues that arose during the workshop. Chapter 2 introduces key policy documents and statements that shape the environment today for discussing the future of the U.S. civil space program and summarizes the opening remarks of ASEB and SSB Chairs William Hoover and Lennard Fisk. Chapters 3 through 8 summarize the panelists' remarks and general discussions of each of the workshop sessions. Appendix D provides biographical material on the workshop speakers, and Appendix E presents extended abstracts prepared by the invited panelists.



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# Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee.  The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge.  The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.  We wish to thank the following individuals for their review of this report:

Lewis Branscomb, Harvard University (Emeritus),
Martin E. Glicksman, Rensselaer Polytechnic Institute,
John Logsdon, George Washington University,
John McElroy, University of Texas at Arlington (retired), and
Dava J. Newman, Massachusetts Institute of Technology.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Mary J. Osborn, University of Connecticut Health Center.  Appointed by the National Research Council, she was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered.  Responsibility for the final content of this report rests entirely with the rapporteurs and the institution.



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# Contents





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# 1
# Summary

The workshop on national space policy was organized to air perspectives on the question, What should be the principal purposes, goals, and priorities of U.S. civil space? Or to simplify, What should be our national space policy? The timing of this workshop coincides with a newly directed focus on the long-term direction of the U.S. civil space program. In the wake of the space shuttle *Columbia* tragedy, the Columbia Accident Investigation Board (CAIB) found that a contributing factor in NASA's organizational decline was the lack of an agreed national vision for human spaceflight. Congress has held several hearings on this topic, the press is commenting on it, and the Bush Administration is developing a new space policy (see Chapter 2).

The workshop's six sessions are summarized in the chapters that follow. Through the course of these sessions several matters were addressed that transcended the subject of any one session in particular, emerging as more general themes relevant to the workshop's principal questions. These seven themes become apparent when one reads the session summaries as a whole and are presented in this summary chapter.

## THEME 1: SUCCESSFUL SPACE AND EARTH SCIENCE PROGRAMS

Many workshop participants (panelists and ASEB and SSB members alike; see Appendix B) accepted that U.S. space and Earth science programs are currently productive and progressing steadily, and they described them as being of continuing importance. Many commented during the workshop on the inspiration, success, and progress of the science programs,[1] and they elaborated in their contributed abstracts on the benefits of the approach taken by the science programs.[2] Much of the success of NASA's science programs was attributed to having clear long-range goals and roadmaps that are framed by scientists and periodically reassessed by the science community in the light of new knowledge and capability.[3] The comments on science were brief, largely because many participants saw the human exploration program as more problematic than the science programs, which were considered healthy and solid. For example, as discussed in Chapter 3, Logsdon challenged the participants to consider that "discussion about the future of the space program would really be discussion about the future of the human spaceflight program. The space and Earth science programs are part of the nation's portfolio of basic research and are not controversial in principle, though budget levels of course are always a concern."[4]

Participants who commented that the science programs were successful noted not just the "facts" of success, but the means by which the science programs achieved their successes. They identified the following attributes of the science programs that are the primary contributing factors for their success:

1. *Participation from the scientific community*. An external-to-NASA constituency that has some "ownership" in the program creates "constructive tension" that pushes the programs to excel.
2. *Clear goals.* The science programs set out explicit goals and utilize the interest of the scientific community to establish these goals (e.g., through the decadal-scale strategy surveys conducted by the NRC).
3. *Strategic planning*. The science programs lay out a strategy for achieving their goals.

[1] See Chapter 4, "Rationales for the Space Program: Science, Technology, and Exploration."
[2] See Appendix E, especially contributed abstracts by Fink, Giacconi, Huntress, Malow, Stone, and Wheelon.
[3] See Malow, "A Tale of Two NASAs," contributed abstract, Appendix E.
[4] See Chapter 3, page 14.



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4. *A sequence of successes.* The science programs progress via a series of individual steps that can accumulate successes that help measure progress and sustain momentum for the program.

A number of participants observed that many of these attributes from the science programs were missing in the human exploration program and saw the opportunity to apply them as lessons learned for the improvement of the human spaceflight program.

## THEME 2: A CLEAR GOAL FOR HUMAN SPACEFLIGHT

Through the course of the day-and-a-half workshop, no participant argued either (1) that we already have a clear human spaceflight goal or (2) that we do not need one. As Chapter 2 suggests, these two points seemed to be part of the context that set the stage for a debate over national space policy.

Many participants echoed the CAIB's conclusion that a lack of an agreed vision for the human spaceflight program has had a negative impact on the health of that program in NASA. Those participants noted that without such a long-range goal the human spaceflight program's *reason for being* is hard to articulate. This is true for the specific elements of the human spaceflight program, the space shuttle and the space station, as well as for the program in general. It is not clear to what end the International Space Station (ISS) contributes or what would be the next logical step after the ISS has served its purpose. This stands in contrast to other programs, like military and commercial space programs, which have more easily stated justifications. Wesley Huntress made a crucial point about why such a goal is necessary in our risk-averse society: Human spaceflight is dangerous and requires risk taking, and the public may support risk taking if there is a clear, understandable purpose. Risk cannot be eliminated, but risk due to poor management or lack of rigor should be minimized. A bold goal could enable breaking out of this programmatic drift, providing a transcendent purpose for the risk of human endeavors in space.

Lennard Fisk's closing statement (Chapter 8) synthesized comments of several others in saying that we no longer need to demonstrate U.S. technological prowess as Apollo did, because there are many such demonstrations, but there is a need to demonstrate U.S. leadership and goodwill. Human spaceflight could provide the opportunity for leadership if the United States would openly invite others to participate in setting and steadily pursuing a shared long-range goal.

## THEME 3: EXPLORATION AS THE GOAL FOR HUMAN SPACEFLIGHT

The nation originally sent humans to space to demonstrate U.S. technical prowess and political will. Why should we do it now? Many workshop participants emphasized two fundamental reasons:

1. Exploration can and does add to the acquisition of new knowledge, that is, knowledge of space as a place for human activity, and knowledge of the solar system, including Earth, from the vantage point of space.
2. Exploration is a basic human desire: people explore. Riccardo Giacconi called it a general impulse of human nature, and others concurred, suggesting that exploration should be the primary motivation of human spaceflight in order to fulfill an innate human need to explore.

As Robert Frosch said, exploration can be the first step of science. He referred to the oceanographic community, noting that scientists want to dive on the *Alvin* and look at the deep oceans because they see



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things and they can get from the experience something that they don't get from remote presentations.[5] Fisk picked up on this point, stating that exploration is a legitimate form of science, if properly conducted. There is a need to incorporate defendable, legitimate science into the human exploration endeavor.

If science can generally be understood as the process through which we acquire new knowledge, then the search for new knowledge may in many ways be akin to humans' innate desire to explore. As such we may think of these two reasons together as "the human desire to know, to learn." It was former astronaut Thomas Jones who most clearly articulated the tie that binds these reasons to the tangible benefits of human spaceflight: Only a human can experience what being in space feels like, and only a human can communicate this to others. Indeed, communication of the space experience is the foundation for the entire cultural aspect of the space program. Several participants agreed with this statement, including Todd La Porte, who stated that the important cultural benefits from the human space program are not always well articulated for the general public to recognize and understand. Better communication of the space experience, therefore, is seen as necessary to maintain the space program's political support among the general public. A strong human spaceflight program can help secure public ownership and involvement in the rest of the civil space program. Several participants enunciated this point and spoke of the need for "heroes" and of how people can have a sense of participation through the participation of these heroes.

This cultural aspect, the communication of the space experience, reveals the unique opportunity that space presents for international cooperation. Norman Neureiter was most eloquent in describing how human spaceflight can be a means to enable fruitful and healing international collaboration. Saying that there is a perception that some in the world may fear our power, Neureiter argued that space exploration can be a compelling instrument for building a global fabric of relationships that dispel that fear—relationships that will endure whatever other bad things may happen. In other words we can increase national security by increasing understanding and trust through cooperation.

Participants described a need for human space exploration because it speaks across cultures to some of our greatest natural characteristics and intellectual curiosity: our desire to learn, to extend our grasp with technology, to modernize, to enhance that which makes us human. They also discussed the need for the nation to set a target for our exploration—a goal or a destination for humans to arrive at (that is, beyond low Earth orbit) as a way to help focus the exploration effort. Whatever the goal, participants argued that it will be decided through the course of a national and international dialogue that should begin now.

Participants expressed the importance of making the goal or destination one that excites the imagination and speaks best to our curiosities. Many of the participants suggested that the goal that best meets these criteria is the eventual human exploration of Mars. Others suggested that a mission to the Moon as a precursor to a human visit to Mars could be valuable, while some even suggested that the eventual human exploration of planetary bodies farther out in the solar system should be considered. Whatever the nation may decide through the course of an open dialogue, what emerged as important considerations for achieving that goal is the subject of the next several themes.

## THEME 4: EXPLORATION AS A LONG-TERM ENDEAVOR TO BE ACCOMPLISHED VIA A SERIES OF SMALL STEPS

Many participants argued that having a clear, agreed upon, long-term goal, such as the human exploration of Mars, is essential for the future success of the human spaceflight program. It was seen as premature, however, to set a firm date for or cost of that goal. What is possible is a first assessment of

[5] See also National Research Council, *Future Needs in Deep Submergence Science: Occupied and Unoccupied Vehicles in Basic Ocean Research*, Committee on Future Needs in Deep Submergence Science, National Academies Press, Washington, D.C., prepublication, 2004.



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what has to be accomplished to reach that long-term goal, and the identification of intermediate, subsidiary goals that can be met as a means to enable the achievement of that long-term goal. In this context the human spaceflight program would be conducted as a series of smaller steps and would evolve at a pace that reflects a meaningful rate of learning. Speakers suggested that this approach requires a coherent architecture or roadmap, which would elucidate how each intermediate step could be accomplished through a sequence of smaller projects that are both technically feasible and acceptable in the political environment.

Several participants observed that a national decision to pursue an ambitious long-term goal would be a political decision, not a scientific one. Therefore such a decision would require political support, which in turn requires realistic costs and broad support. Regarding costs, several participants suggested that the response to a statement by Congressman Sherwood Boehlert that "any vision that assumes massive spending increases for NASA is doomed to fail"[6] should be one in which the nation agrees to pursue a long-term goal with a "buy it by the yard" approach. The big challenge of attaining the goal would be broken into many small achievable challenges. Instead of a fixed deadline, the budget would fund only as many of the "small steps" as could be afforded. Participants talked about an exit strategy for the shuttle and the space station, and, if adopted, that strategy could free up funds.

On the issue of coalitions of support many participants recognized the need for a process different from that used to build support for the space shuttle and space station programs. Frosch was most clear on this point. Recalling his experience as NASA's administrator, he noted that instead of promising something for everyone, we must strive to establish a coalition that agrees on a specific space exploration goal. Even if different members of the coalition have different motivations for this goal, there must be agreement on the goal itself. Similarly, there was much discussion on the role of international partners in a coalition for support of a long-term goal. The smaller steps envisioned here offer many opportunities for partner governments to contribute and be involved as true stakeholders in the program. The successes, accumulated in many small steps, will help to build political support. That is, if projects are evaluated against the agreed goal, the workshop discussions envisioned that after many milestones are achieved, and numerous small, cumulative steps are taken, the long-term goal will become inevitable.

## THEME 5: SYNERGY SUPERSEDING THE HUMANS-VERSUS-ROBOTS DICHOTOMY

In the ultimate achievement of a long-term goal for human exploration, numerous participants made statements echoing the spirit of the remarks made by Congressman Ralph Hall, quoted in Chapter 2: "There should no longer be a question of robotic versus human exploration—clearly both will be needed. . . ." Fink recalled his experience with the Augustine Committee,[7] noting that in the early 1990s there was an unnecessary tension and debate on the subject of "manned versus unmanned" exploration. He noted that this debate has passed and that planning for exploration beyond low Earth orbit will have to consider how to best utilize both human and robotic assets. Other participants agreed, stating further that they believed the space program should move beyond complementarity and toward a synergy between robots and humans, as the concept of synergy best highlights the potential benefits associated with taking advantage of the strengths of each.

Exactly how best to realize this synergy is a matter that requires further discussion and can be dependent on what destination is chosen as the eventual goal for human exploration. In her prepared remarks, Newman articulated this point explicitly, noting that human-robotic missions could take the form of humans assisted by robotic explorers or robots/probes assisted by humans who are not co-located, depending on the location being explored. Frosch was even more detailed, discussing how robots and humans could be integrated if Mars were chosen as the human exploration goal; we could begin with

[6] See Chapter 2 for Mr. Boehlert's statement.
[7] Advisory Committee on the Future of the U.S. Space Program, *Report of the Advisory Committee on the Future of the U.S. Space Program*, December 1990, U.S. Government Printing Office, Washington, D.C.



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teleoperations from Mars orbit and guided autonomy on the ground, after which we could move to the surface of Mars where humans can undertake tasks that robots cannot perform. Whatever the destination and whatever the specific means chosen, many participants stated that being guided by a principle of synergy between robots and humans provides the opportunity to explore the solar system in the most optimal manner.

The participants noted that there are additional benefits to the synergy of human and robotic assets. One is the fact that it provides the opportunity to communicate the space experience, as Jones expressed. Fink noted that this was a conclusion reached in the Augustine Report as well. Another is the opportunity that a human presence creates for unanticipated learning. Building on Fisk's assertion that good science can be done with properly devised exploration efforts, Frosch again cited the desire for human participation in the exploration of the deep sea. Newman referred to this as humans enabling serendipity through the co-exploration of space with robots.

In summary, while a history of separation between human and robotic efforts is part of the context, many participants, notably including many scientists, seemed to believe that now is the time to put the dichotomy behind us and to find and exploit synergies between the two.

## THEME 6: THE LONG-TERM GOAL DRIVING ALL IMPLEMENTATION DECISIONS

Many participants confirmed the context described in Chapter 2, i.e., that both the space shuttle and space station programs made too many promises to too many people and thus lost focus on any one technical mission. Yet if the human exploration program had a goal involving long-term human spaceflight, the station could have a very clear justification: to conduct microgravity and variable-gravity research and technology development to support the agreed goal. To many participants, this meant a higher priority for biological research in support of long-duration spaceflight. Indeed, participants argued that soundly based research on scientific and technical problems tied to human exploration beyond low Earth orbit should be the primary purpose of the ISS. The key to successful experiments lies in investigating gravity as an independent variable, whereby biological and physical processes in the weightless environment can be quantified. In addition to the microgravity research conducted on the ISS, participants argued that this approach means an additional focus on experiments utilizing fractional gravity—experiments that may be possible only with a variable-gravity research centrifuge aboard the ISS.

Others noted that learning how to stage and construct large systems, e.g., a large telescope, at a space station and move it to its operational orbit would realize and demonstrate the synthesis of robotic and human activities. Similarly, a human exploration goal could well raise new missions for the ISS, and ultimately, the goal of extending human presence beyond Earth orbit could define the exit strategies for the space station program. The thrust of these comments was that, given a human exploration goal, the ISS program should be modified to focus on supporting that goal, which would mean completing construction of needed facilities and choosing the right experiments to fly on the station. In other words, there would be very clear criteria for setting priorities across the program.

As with space station, the state of the shuttle program is a relevant part of the context of which workshop participants were well aware. The CAIB referred to the original promises and compromises required to gain approval for the shuttle program. These ensured there would be pressure for the vehicle to deliver more than it could. Participants argued that the shuttle program is now at a crossroad and the nation is faced with difficult choices—try to fix and continue with the shuttle or develop another launch vehicle. Discussions focused on the idea that a new human exploration goal could not only provide criteria for this decision, but could also make it possible to define a general exit strategy for the shuttle.

In summary, participants appeared to view the following activities as essential elements along the path to a goal for human exploration: (1) the continued robotic exploration of our solar system followed by the development of capable human-machine interfaces and teleoperators, (2) research on the ISS focused on addressing the questions posed by human exploration away from low Earth orbit, and (3)



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development of a space transportation system to replace the shuttle, all directed toward facilitating the eventual human exploration of some destination beyond low Earth orbit.

## THEME 7: INSTITUTIONAL CONCERNS

These first six themes are cross-cutting concepts relevant to the nation's future approach to civil space. The seventh theme collects the views offered by participants on needs and opportunities for successful implementation of future space policy.

Concerning the needs of all U.S. space activities, participants cited the *Final Report of the Commission on the Future of the United States Aerospace Industry*[8] and pointed to the need for an "industrial base." Critical cross-institutional or cross-sector activities—e.g., joint technology development, taking advantage of synergies, and better planning and development—are all dependent on the availability of a skilled industrial base. This base was viewed as being in decline.

Regarding the civil space program, workshop discussions primarily addressed two particular stakeholders in future civil space activities. They were (1) NASA, as the primary executive branch agency responsible for implementing space policy, and (2) the scientific community, one of NASA's key constituents.

### NASA

Workshop discussions focused on the following five aspects of NASA as an institution:

1. *Lack of human spaceflight stakeholders*. Participants were attracted to an intriguing observation about human spaceflight in comparison with the science program. In the science program scientists set the goals, e.g., scientific questions to be answered by desired missions, and the agency carries them out. In this way NASA and the scientists share the direction of the program. The scientists have a big stake in the agency program, but there is always tension between the scientists who want as much science as possible and who honor scientific values, and the implementers who face the practicalities of resource limitations. Noel Hinners found this tension creative, resulting in better science, and noted the lack of similar independent stakeholders and creative tension in the current human spaceflight program. La Porte noted that his research on high-reliability organizations shows that they tend to have a strong presence of, and often active coordination with, outside stakeholder groups.

2. *NASA's changed role*. Participants noted that at NASA's beginning its job was to help make the United States a space-faring nation, but today the United States would be a space-faring nation even if NASA disappeared. Now, they suggested, the agency's new role is to advance several space frontiers: science, human physiology, applications, technology, and human exploration.

3. *Trust and honesty*. Chapter 2 quotes Representative Boehlert, who has said that "we need to be honest about the purposes and challenges" of human spaceflight. Several participants cited less than forthright justifications for programs, from Apollo to the present. Several noted that more candid justifications of programs would help justify the risk of spaceflight; the public is not risk-averse for worthwhile programs. More openness would improve trust. In addition, Neureiter noted that failing to involve one's partners at the very beginning of program decision making damages one's credibility as a partner. Others agreed that NASA cannot afford to be seen as less than fully open and honest.

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[8] Commission on the Future of the United States Aerospace Industry, *Final Report of the Commission on the Future of the United States Aerospace Industry*, Arlington, Virginia, 2002.



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4. *Management competence*. The NASA ISS Management and Cost Evaluation (IMCE) Task Force report,[9] part of the workshop's context, found that the ISS program lacked the skills and tools to control costs and schedules. Noting the conclusions of the CAIB report, participants observed that in both the *Challenger* and *Columbia* accidents NASA management demonstrated failure to detect and remedy the early onset of failures that would threaten the safe operation of the space shuttle. Managers were not seen as learning across generations; they repeat mistakes. Participants also felt that NASA managers overpromised and got into trouble on the shuttle and then did the same thing 10 years later on the ISS.

5. *Technical competence*. Several participants commented that NASA tended to freeze old technology into human spaceflight programs. As a result, these programs may have trouble attracting good technical people who are at the cutting edge, or younger engineers and scientists.[10] NASA was described as maintaining the shuttle and the station rather than developing new technology.

## The Scientific Community

Fisk concluded the workshop by saying that he believed that this workshop could be a truly historic event if the scientific and technical communities, in the broadest sense, can say that as a group "we believe in a human spaceflight program, we believe this country should invest in it, and we will stand up and say how it can be done productively." Participants saw this as a realistic possibility for several reasons. First, the timing seems good, because the robotic-versus-human dichotomy has begun to dissipate. Second, the tradition in space and Earth science, in which there exists a constructive tension between the agency and scientists who act as continuous stakeholders, was viewed by many as a model by which scientific exploration could strengthen human exploration. Third, participants seemed to agree that the science community could constructively help NASA identify and carry out the best science possible over the course of human exploration missions. Fourth, the discussions suggested that there is an important role for scientists to become involved as stakeholders in helping to integrate humans and robotics in the kind of synergistic way described above, thus producing the best experiments and missions possible and ensuring that bargains are kept across management generations. Indeed, this last point may represent one of the most important and hopeful ideas to emerge from the workshop.

[9] Report by the International Space Station (ISS) Management and Cost Evaluation (IMCE) Task Force to the NASA Advisory Council, November 2001. Available at <http://history.nasa.gov/youngrep.pdf>; accessed, December 9, 2003.
[10] See discussions in Chapter 8 on this point.



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# 2
# Introduction

This chapter identifies several key policy statements and documents that have shaped the current environment in which the future of the U.S. civil space program and a national policy on civil space is being considered; this is the national context in which the SSB-ASEB workshop took place. This chapter also summarizes the opening remarks of ASEB Chair William Hoover and SSB Chair Lennard Fisk. The remaining chapters of this workshop report provide summaries of each of the six sessions comprised by the nearly 2-day workshop. Together these chapters represent the proceedings of the workshop sessions.

## ORGANIZATION OF THE WORKSHOP

Session 1 was a review of space policy history and the lessons learned from our past experiences (Chapter 3). Session 2 examined what may be considered a more traditional rationale for the civil space program—the benefits of science and exploration (Chapter 4). Session 3 looked at a much broader context or rationale for the nation's space program as a whole, including issues related to national security, foreign policy, and the commercial benefits of space (Chapter 5). Session 4 was an opportunity to consider some of the principles that a national space policy should address and the needs that space policy should fill (Chapter 6). Session 5 examined the political environment that establishes a kind of boundary condition for the space program and therefore can help define a realistic path for the space program (Chapter 7). The final session, a wrap-up discussion, was an opportunity for the participants to share what they thought they had heard, and an opportunity to reflect on what key themes had emerged from this workshop (Chapter 8). The sessions were organized in such a way that each of the guest panelists was asked to say a few words, after which the remaining time was open for discussions directed by session moderators.

## CONTEXT FOR THE WORKSHOP

After the tragedy of the *Columbia* accident in February 2003, the SSB and the ASEB recognized that a new level of national attention was being directed toward NASA and the nation's civil space program. Before the accident, it had been a growing matter of concern to both Boards that our current national program of human spaceflight—the International Space Station (ISS) and the space shuttle—was restricted to low Earth orbit for the foreseeable future and did not constitute exploration in any reasonable sense of the word. The *Columbia* accident brought this situation inescapably into focus. The *New York Times* ran an editorial entitled "The Challenge Ahead in Space,"[1] questioning "whether to pour large sums into such near-space activities or go instead for something grander and more stirring." A *Science Magazine* news story entitled "Vision, Resources in Short Supply for Damaged U.S. Space Program"[2] summarized the situation. In that story NASA Administrator Sean O'Keefe was quoted as calling this time "a seminal moment in the agency's history." The following paragraphs elaborate on this context in more detail.

The *Columbia* accident revealed flaws in the shuttle program. The Columbia Accident Investigation Board (CAIB)[3] found an unhealthy, unsafe culture at NASA:

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[1] "The Challenge Ahead in Space" in Week in Review, *The New York Times*, July 6, 2003, p. 8.
[2] Andrew Lawler, "Vision, Resources in Short Supply for Damaged U.S. Space Program," *Science*, September 5, 2003, pp. 1300-1303.
[3] Columbia Accident Investigation Board, "Report 1, Volume 1," August 2003, p. 9. Available at < http://www.caib.us/news/report/volume1/default.html >; accessed December 1, 2003.



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> The organizational causes of this accident are rooted in the Space Shuttle Program's history and culture, including the original compromises that were required to gain approval for the Shuttle, subsequent years of resource constraints, fluctuating priorities, schedule pressures, mischaracterization of the Shuttle as operational rather than developmental, and lack of an agreed national vision for human space flight. Cultural traits and organizational practices detrimental to safety were allowed to develop, including: reliance on past success as a substitute for sound engineering practices (such as testing to understand why systems were not performing in accordance with requirements); organizational barriers that prevented effective communication of critical safety information and stifled professional differences of opinion; lack of integrated management across program elements and the evolution of an informal chain of command and decision-making processes that operated outside the organization's rules. (p. 9)

Further, the CAIB stated its opinion that "unless the technical, organizational, and cultural recommendations made in this report are implemented, little will have been accomplished to lessen the chance that another accident will follow" (p. 6). It found "striking" parallels with the 1986 *Challenger* accident, where NASA had accepted deviant erosion of seals in the booster rocket (p. 130). In other words, history gave the CAIB reason for concern that its recommendations might not be implemented.

The space station program has faced difficulty in fulfilling the promises that justified the program. For example, the executive summary of the 2001 NASA ISS Management and Cost Evaluation (IMCE) Task Force report included the following findings, among others:

> The U.S. Core Complete configuration [one end-point for Station development] will not achieve the unique research potential of the ISS. . . . NASA has not accomplished a rigorous ISS cost estimate. The program lacks the necessary skills and tools to perform the level of financial management needed for successful completion within budget. . . . The cost to achieve . . . expectations at assembly complete [a different end-point] has grown from an estimate of $17.4B to over $30B. Much of this cost growth is a consequence of underestimating cost and a schedule erosion of 4+ years . . . .The Program is being managed as an institution rather than as a program with specific purpose, focused goals and objectives, and defined milestones [e.g., a single, clear end point for development].[4]

In short, it remains unclear whether the space station program is on a path to achieve promised capabilities—for example, to provide adequate facilities for life science research. On the other hand, it is clear that on its present path the station program is likely to continue to absorb significant budget resources.

Following the *Columbia* accident and the CAIB report, Congress began holding several hearings to address issues related to the future of the space program. In testimony at the Senate Commerce Committee's hearing on the CAIB report,[5] Senator John McCain said,

> The Board's final report . . . must serve as a wake-up call to NASA and to the nation that we have for too long put off hard choices, and forced the space program to limp along without adequate guidance or funding. . . . Most importantly, we will have to figure out where we want the space program to go, and what we expect to get out of it.

In opening a hearing on the future of human spaceflight Congressman Sherwood Boehlert, chair of the House Science Committee, said,[6]

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[4] Report by the International Space Station (ISS) Management and Cost Evaluation (IMCE) Task Force to the NASA Advisory Council, November 2001. Available at <http://history.nasa.gov/youngrep.pdf>; accessed December 9, 2003.

[5] The Testimony of the Honorable John McCain, Chairman, U.S. Senate Committee on Commerce, Science, Transportation. Given at a Full Committee Hearing: Columbia Accident Investigation Board (CAIB) Report on Shuttle Tragedy, September 3, 2003.

[6] House Science Committee, Thursday, October 16, 2003, "Rep. Boehlert's Opening Statement: Hearing on the Future of Human Space Flight."



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> 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.

Boehlert laid out five principles to be considered in developing a national consensus about the future of human spaceflight:

> 1. 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.
> 2. 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.
> 3. 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.
> 4. 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.
> 5. 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.

At the same hearing, Representative Ralph Hall said,[7]

> 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 is 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.

In introducing his proposed National Space Commission Act of 2003, Senator Ernest F. Hollings said,

> Let me reiterate. Merely announcing a bold new plan to travel to the Earth's Moon or to Mars is not sufficient. If the loss of the Space Shuttle Columbia merely results in that proposal, we will have failed the memory of our brave astronauts who lost their lives aboard both Challenger and Columbia. And we will have failed our own future.
>
> Unfortunately, our current charge is more difficult. We must challenge our assumptions, question our decisions and designs, revisit our approaches, and rethink our Nation's ambitions and goals for space. We must submit ourselves to the discipline to begin anew. The future of space and our Nation's reputation that we carry into history rests in the balance.[8]

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[7] Office of Rep. Ralph Hall, released Thursday, October 16, 2003, "Opening Statement by Rep. Ralph Hall at hearing on the Future of Human Space Flight."

[8] Office of Senator Ernest F. Hollings, released November 6, 2003, "U.S. Senator Ernest F. Hollings' Floor Speech on Introduction of the National Space Commission Act of 2003, November 5, 2003."



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Neither the CAIB report nor this workshop report are the first to review issues of national space policy at the highest level. Several studies over the last 20 years have noted the need for a clear goal for the human exploration program. For example a 1988 NRC report[9] noted,

- "Even greater benefits can flow from future space activities if they are guided by clear goals" (p. 1).
- "Strong leadership by the President" is needed to determine the direction of the program (p. 2).
- "Manned space flight is a necessary element of space leadership . . ." (p. 3).

In other words, for the United States to be a leader requires that human spaceflight have clear goals supported by the President and Congress. At present, the nation lacks such a goal.

The Augustine Committee[10] was particularly prescient in reaching conclusions very like those of the CAIB. It listed several concerns, the first two of which were:

1. "The lack of a national consensus as to what should be the goals of the civil space program and how they should in fact be accomplished."
2. "NASA is currently over committed in terms of program obligations relative to resources available." (p. 2)

It concluded that "America does want an energetic, affordable and successful space program" as evidenced by the consistent funding growth that had been experienced at that time. (Since then NASA has seen its budget shrink, but recently it has resumed modest growth.) The Augustine Committee recommended manned space exploration—explicitly "the human exploration of Mars"—but also stated, "Today, America's manned space program is at a crossroads" due to lack of a national focus on this goal, which may cause the program "to drift through the decade ahead" (pp. 5-6). It believed that "a program with the ultimate, *long-term* objective of human exploration of Mars should be tailored to respond to the availability of funding, rather than to adhering to a rigid schedule," not because it is unimportant but because "we cannot know with any exactness the cost or obstacles which may impede a Mars mission" (p. 6). It also believed that the space station could be justified only as a life sciences laboratory to "gain the much needed information and experience in long duration space operations" (p. 6). Finally, the Augustine Committee called for development of "a reliable, unmanned vehicle that complements the Space Shuttle and that can be used for routine space trucking, saving the Space Shuttle for those missions requiring human presence."

The CAIB looked ahead, beyond short-term recovery from the *Columbia* accident, and echoed many of the Augustine Committee findings. The CAIB assumed that the United States wants to retain the "capability to send people into space" (p. 211) and noted two related realities:

1. "Lack, over the past three decades, of any national mandate providing NASA a compelling mission requiring human presence in space." This made it difficult to get the needed budget, resulting in "an organization straining to do too much with too little."
2. "Lack of sustained government commitment over the past decade to improving U.S. access to space by developing a second-generation space transportation system." (p. 209)

All members of the CAIB agreed that "America's future space efforts must include human presence in Earth orbit, and eventually beyond . . . " (p. 210). Based on its careful examination of the shuttle program, the Board "reached the inescapable conclusion" that because of the shuttle's risk, age, and

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[9] NAS-NAE Committee on Space Policy, *Toward a New Era in Space*, National Academy Press, Washington, D.C., 1988.

[10] Advisory Committee on the Future of the U.S. Space Program, *Report of the Advisory Committee on the Future of the U.S. Space Program*, December 1990, U.S. Government Printing Office, Washington, D.C.



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developmental character, "it is in the nation's interest to replace the Shuttle as soon as possible as the primary means for transporting humans to and from Earth orbit" (p. 210). The design of the shuttle replacement should give top priority to crew safety, rather than, for example, trading safety against low-cost, reusability, cargo capacity, or advanced space operation capabilities (p. 211). A next-generation transportation system beyond this replacement vehicle should support any new national goal established.

While concerns have been expressed that the human exploration program is drifting without a clear mandate or mission, there is a sense throughout the reports cited above and many others that the robotic science programs are not drifting. The science programs have a similar problem of overcommitment, but it is a result of lack of discipline and resources in following up the programs' many successes. Science has been able to set its own goals and priorities.[11]

Any discussion of context must also note the broader policy environment, including the national security and commercial space activities, the new Chinese human spaceflight program, the worldwide war on terror, substantial and continuing deficits, an unfavorable balance of trade, and an erosion in the U.S. standing in the world. This is a list of issues that are facing the Congress, the Bush Administration, and the nation as whole, and they provide the context within which a national dialogue on the future of space policy will take place. While addressing these particular issues specifically was not within the scope of the workshop, participants were aware of their potential impact on space policy when conducting their discussions.

## KEYNOTE REMARKS

Aeronautics and Space Engineering Board Chair William Hoover opened the workshop by welcoming all the participants and thanking the staff of the Space Studies Board and the Aeronautics and Space Engineering Board for their efforts in organizing the workshop. The interests of these two Boards are a good marriage of the issues identified for examination over the course of the workshop. Hoover noted that the idea for a broader national discussion on space policy initially surfaced after the *Columbia* tragedy. This workshop may be a good thing to do in its own right but would probably not be at its current level of importance if it had not been for that tragedy. This is perhaps a sad example of the law of unintended consequences.

Hoover observed that often a discussion of space policy will evoke one of two responses. One response is to say "there is no policy," when in fact there is, but those who are commenting do not personally agree with it. The second response comes from those who say, "We have no policy, but we are pursuing it vigorously." As daunting as the issues faced by the workshop are, an equally difficult task will be to contribute to moving the nation beyond either of those two responses.

Space Studies Board Chair Lennard Fisk opened his remarks by welcoming the participants as well. He indicated that he had great expectations for the workshop, hoping for an informed and enlightened discussion of this important national issue, with ideas emerging that would be useful to the Congress, the administration, and the broader interested public. Fisk discussed his belief that all of the participants, as well as the broader space community, are deeply concerned about the future of the U.S. civil space program. It is at a crossroads, where some of the glories of the past have begun to fade, and the prospects of a successful future are uncertain. It is in this context that the workshop should develop and articulate ideas about the purpose of the space program and about approaches for the preservation, continuation, and enhancement of this important national endeavor.

In general, Fisk said, we often say positive things about the space and Earth science programs. The universe turns out to be an interesting place. We have the technology to go anywhere in the solar system

[11] For example, see National Research Council, Space Studies Board, letter report on "Assessment of the Draft 2003 Space Science Enterprise Strategy," from Dr. John H. McElroy, SSB chair, to Dr. Edward J. Weiler, NASA Associate Administrator for Space Science, May 29, 2003.



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with robotic spacecraft and to observe Earth, the planets, and the surrounding universe. Thus there is a cornucopia of opportunities, and it remains simply to choose the best ones we can afford.

However, said Fisk, we tend to say less positive things about the human side of the space program. We have no destination other than low Earth orbit. We have an aging and obviously fragile launch capability for humans. We have an expensive space station, whose role and function are at times hard to articulate. It has become obvious, Fisk indicated, that this area of NASA, more than any other, is in need of clearly articulated goals.

Fisk made it clear that he believes there are bigger issues still. The U.S. civil space program is a creation of the Cold War. If there had not been that chapter in our history, would NASA and the space program bear any resemblance to their current form? There is no Cold War today, so what is the justification for the nation's investment? What is the relevance of the civil space program today and tomorrow? Fisk asked, "Are our glory days in the past?" He said he believes we need to find a valid, defendable reason for the relevance of the space program on the national agenda, or it will be in danger of becoming an historical curiosity, an artifact of a unique time.

Fisk indicated that he wanted the workshop to be at a higher level than "NASA bashing." NASA is a creature of the political process, said Fisk. Its current infrastructure was sized to pursue the Apollo program and distributed in part by a political process. The natural bureaucratic instinct of NASA is to preserve what it has and to pursue projects for which there is, at least contemporaneously, the political will to provide support. The discussions on space policy over the course of the workshop, Fisk noted, should be at a higher level. The questions that should be addressed include: What does the nation need from the space program? What should the nation be doing in space, and why? What will the nation support? If these questions are addressed, then the workshop can consider a more directed question: What should NASA become to achieve national goals?

Fisk said that the basic premise of the workshop is that the United States needs to make fundamental changes in its civil space policy. But with the burdens of its existing hardware and infrastructure and its responsibilities to execute what is currently underway, NASA is hard-pressed to define what these fundamental changes should be.

At the end of the workshop, Fisk said, it may be the case that the participants were not able to answer any of these fundamental questions. It is more important, however, that they begin the right debate. Furthermore, there may not be agreement on what the answers should be, but the point of the workshop is not necessarily to come to an agreement either. Rather, the purpose is to introduce into public discussion the issues that a valid space policy has to take into account and deal with. Therefore, said Fisk, it is the job of the participants to raise the discussion above sins of omission and commission and the constraints of the past. The workshop needs to be realistic about what is possible in the current or future political environment, but not overly constrained by the evolutionary path that NASA has followed. The workshop, according to Fisk, must ask what is the right path for the nation to follow in space, and then ask how we can set about finding and following that path.

Fisk noted that the timing of the workshop was opportune. Congress is worrying about the future of the U.S. space program, the press is commenting on it, and the administration is reported to be developing a new space policy that is supposed to be announced soon. He said he hoped that the workshop could develop some constructive thoughts for all of those who are worrying about or commenting on this important national issue.

Fisk closed his remarks by briefly reviewing the outlines and objectives of each session (as described at the opening of this chapter). He invited everyone to read the speakers' biographical summaries (Appendix D) that were made available before the workshop, along with other material supplied by the SSB and ASEB staff. The panelists also prepared brief written materials to supplement their comments prior to the workshop. Those abstracts were also available (Appendix E). He then invited John Logsdon to open Session 1.



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# 3
# Origins of U.S. Space Policy

The first session was introduced by John Logsdon (moderator) of George Washington University and Howard McCurdy of American University, both of whom are space historians and political scientists. The objective of this session was to review the history of space policy in the United States, its origins, and its evolution. The panelists would also lend their perspectives on how the lessons learned from this history have implications for the questions facing the space program today.

Logsdon opened the discussion by reminding the participants about the 1988 National Academies report entitled *Toward a New Era in Space*.[1] This report was one of the documents that influenced the George H.W. Bush Administration to propose a set of challenging goals for the space program on July 20, 1989. The goals proposed by the then-Bush Administration were never implemented, but there was a direct link between the report's claim that the space program needed new goals and the Bush administration's decision to try to propose new goals. The point of bringing this up, Logsdon indicated, was to make it clear that, given the precedent set by the 1988 report, this particular workshop could have a real impact on policy.

Logsdon said that he thought it was valuable to take time to review the history of the space program to determine where it stands now. What is the state of the program now? The overall national space program has been shown to be in serious trouble—even before the *Columbia* accident. When the current Bush Administration came to Washington the International Space Station was $5 billion over budget, and NASA's credibility was at a very low point. On top of that came the *Columbia* accident and the Columbia Accident Investigation Board's findings of organizational problems at NASA. Equally troubling, though not necessarily the subject of this meeting, is the state of the national security space program. Logsdon referred to a report of the Defense Science Board made public in September 2003, which indicated that the national security space enterprise is broken in terms of the ability to be on schedule, deliver technical performance, and meet national objectives.[2] How much are these problems caused by the lack of any clear goals for the space program? Logsdon said that the workshop participants would have to answer that question.

Logsdon said his hope was to detail for the participants the kinds of rationales that have been offered for the space program in the past, and he challenged the participants to consider that over the course of the workshop, discussion about the future of the space program would really be discussion about the future of the human spaceflight program. The space and Earth science programs are part of the nation's portfolio of basic research and are not controversial in principle, though budget levels of course are always a concern.

Moving on to his discussion of history, Logsdon began by pointing out that the first president to address space policy, President Eisenhower, liked statements of policy to be formal and well articulated. Space policy was no different. Logsdon noted that in the late 1950s, the space program was regarded as relevant first and foremost to national security. This included human spaceflight, which was one of the

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[1] NAS-NAE Committee on Space Policy, *Toward a New Era in Space*, National Academy Press, Washington, D.C., 1988 (also known as the Stever Report, for the committee chair H. Guyford Stever).

[2] "Acquisition of National Security Space Programs: Report of the Defense Science Board / Air Force Scientific Advisory Board Joint Task Force on Acquisition of National Security Space Programs," May 2003 (released September 4, 2003). The findings and conclusions of this study team identified requirements definition and control issues; unhealthy cost bias in proposal evaluation; widespread lack of budget reserves required to implement high-risk programs on schedule; and an overall under-appreciation of the importance of appropriately staffed and trained system engineering staffs to manage the technologically demanding and unique aspects of space programs. The report recommends both near-term solutions to serious problems in critical space programs as well as long-term recovery from systemic problems.



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most important pieces as a means of defining national power and national pride.[3] Logsdon suggested that the human spaceflight contribution to projecting power and pride was a theme for at least the first 25 to 30 years of the U.S. space program.

Eisenhower's approach to a "space race," according to Logsdon, was to do as quickly as possible, before the Soviet Union, those things that the nation would be doing in space anyway based on their intrinsic military, scientific, or technological value, as technological capabilities developed. This approach changed with President Kennedy who, after the successful launch of cosmonaut Yuri Gagarin and the failed Bay of Pigs invasion in Cuba, felt more compelled to engage the Soviet Union in a more conspicuous space race. Kennedy's question was,

> Do we have a chance of beating the Soviets by putting a laboratory in space, or by a trip around the moon, or by a rocket to land on the moon, or by a rocket to go to the moon and back with a man? Is there any other space program which promises dramatic results in which we could win?[4]

Logsdon said that a race to a Moon landing was determined to be one that technically the United States could win; "with a strong effort, the United States could conceivably be first in [circumnavigating and landing on the moon] by 1966 or 1967."[5] Others in the Kennedy Administration also recognized a greater value to successful human spaceflight. Both Secretary of Defense Robert MacNamara and NASA Administrator James Webb articulated how successful human spaceflight could have its greatest impact in a psychological capacity:

> Dramatic achievements in space, therefore, symbolize the technological power and organizing capacity of a nation. Major successes . . . lend national prestige even though the scientific, commercial, or military value of the undertaking may by ordinary standards be marginal or economically unjustified. *This nation needs to make a decision to pursue space projects aimed at enhancing national prestige.* [emphasis in original] The non-military, non-commercial, non-scientific but "civilian" projects such as lunar and planetary exploration are, in this sense, part of the battle along the fluid front of the Cold War.[6]

Winning the space race was thus part of winning the Cold War in the broadest sense. Kennedy's acceptance of this rationale, according to Logsdon, may have been the last time there was a clear political rationale and well-articulated policy for the space program. Logsdon pointed out, however, that Kennedy was all the while still looking to pursue opportunities for cooperation in space with the Soviet Union.

After the completion of Project Apollo, NASA had to get approval for one or more new programs to keep its engineering capabilities fully employed. Logsdon labeled NASA's desired goal the "Von Braun paradigm" (i.e., a space station and a shuttle to supply the station, then permanent outposts on the Moon followed by missions to Mars). However, the White House rejected the idea of anything too big, so NASA decided to pursue the shuttle first.[7] During the debate over the shuttle, some officials at the Office of Management and Budget (OMB) wanted to reduce the human spaceflight program. Showing a copy of

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[3] National Security Council, NSC 5814, "U.S. Policy on Outer Space," June 20, 1958, available in Logsdon, John M., *Exploring the Unknown: Selected Documents in the History of the U.S. Civil Space Program, Volume I, Organizing for Exploration*, NASA History Series, 1995.
[4] John F. Kennedy, Memorandum for Vice President, April 20, 1961, in Logsdon, *Exploring the Unknown,* 1995. The memo was displayed by Logsdon during his presentation.
[5] Lyndon B. Johnson, Vice President, Memorandum for the President, "Evaluation of Space Programs," April 28, 1961, in Logsdon, *Exploring the Unknown,* 1995.
[6] James E. Webb, NASA Administrator, and Robert S. McNamara, Secretary of Defense, to the Vice President, May 8, 1961, with attached: "Recommendations for Our National Space Program: Changes, Policies, Goals," in Logsdon, *Exploring the Unknown*, 1995.
[7] For more information on options in the space program after the completion of Project Apollo, see *The Space Program in the Post Apollo Period* (Lewis M. Branscomb and Frank E. Long, co-chairs), Report of the Space Science and Technology Panel of the President's Science Advisory Committee, Washington D.C., The White House, 1967.



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a memo from then OMB Deputy Director Casper Weinberger, however, Logsdon indicated that human spaceflight, and in particular the shuttle, were still seen as a symbol of determination, national will, and national power. Weinberger argued that the United States should be able to afford something more than increased social services for its citizens. To turn away from space would be to say that the best days of NASA were already passed. President Nixon indicated his support for the shuttle with a simple note on Weinberger's memo: "I agree with Cap."[8] Logsdon wondered whether China's pursuit of manned spaceflight might be used in a similar fashion today. He cited NASA Administrator James Fletcher's argument to the White House in November 1971 that for the United States not to have humans in space while others (at that time the Soviets) did was an unacceptable position for this country.

Logsdon moved his discussion into the 1980s. NASA was still continuing along the Von Braun paradigm, setting a space station as its next goal. Logsdon indicated that continuing to pursue the Von Braun paradigm was a way to continue to push the idea of human spaceflight as a matter of national strength and leadership. In presenting the space station to President Reagan, NASA described it as "a highly visible symbol of national strength." But NASA officials found the political environment difficult to operate in, so they had to do more to justify the program. Workshop participant Edward Stone pointed out that in 1983 then NASA Administrator James Beggs came to the Space Studies Board asking for a scientific rationale for the station. The Board's reply was to indicate that if there was a station, scientific uses could be found for it, but a station wasn't needed for good science.[9]

Logsdon noted that decisions to proceed with Project Apollo, the space shuttle program, and the space station have been the defining events for the U.S. space program. Maybe getting Russia into the ISS program was also a defining element, he added. Certainly, the first three were all pursued primarily because a national program in human spaceflight was seen as a way of projecting national power and prestige. Logsdon suggested that the workshop participants consider whether power and prestige are any longer sufficient justifications.

In closing Logsdon displayed the last national space policy from September 1996.[10] The policy clearly stated that NASA's first priority in human spaceflight was completing the ISS:

> (3) To enable these activities, NASA will:
>
> (a) Develop and operate the International Space Station to support activities requiring the unique attributes of humans in space and establish a permanent human presence in Earth orbit. The International Space Station will support future decisions on the feasibility and desirability of conducting further human exploration activities.[11]

Howard McCurdy opened his remarks by stating that the problem with the space program is that U.S. officials refuse to commit to a real goal. He asserted that the history of the human spaceflight effort is one of leaders refusing to make long-term commitments. Citing an article in *Public Administration Review* by political scientist Charles Lindblom titled "The Science of Muddling Through,"[12] McCurdy argued that NASA has adopted what Lindblom described as the politics of incrementalism. NASA adopted incrementalism as its way to achieve the Von Braun paradigm. NASA wanted both the space station and the shuttle but had to get them one step at a time.

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[8] Casper Weinberger, Deputy Director, Office of Management and Budget, via George P. Schultz, Memorandum for the President, "Future of NASA," August 12, 1971, in Logsdon, *Exploring the Unknown*, 1995.
[9] Space Science Board, National Research Council, "Space Science Board Assessment of the Scientific Value of a Space Station," letter report from SSB Chair Thomas M. Donahue to NASA Administrator James M. Beggs, September 9, 1983.
[10] Presidential Decision Directive / National Science and Technology Council – 8. "Fact Sheet: National Space Policy," September 19, 1996.
[11] National Science and Technology Council, "Fact Sheet – National Space Policy," September 19, 1996.
[12] Lindblom, Charles, E., "The Science of Muddling Through," *Public Administration Review*, Vol. 19, 1959, pp. 78-88.



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McCurdy said that with incremental policy making people do not have to agree on the long-term goals, but rather they have to agree that the policy of taking steps is a good idea. Getting the first approval for the first step requires building coalitions of political support. That is a political necessity, but coalitions will lead to additional program objectives—objectives that are hard to realize in a technical sense if too many additional objectives are added to a program. In the end, these additional objectives compromise a program's technical capabilities in comparison to its originally intended purpose. McCurdy said this is exactly what happened with the space shuttle.

Having had the opportunity to learn this lesson once with the space shuttle, McCurdy said that NASA made the same mistakes all over again with the space station. When it was originally conceived, there were several ideas on how to best utilize a space station. Like the space shuttle, NASA's leadership built a coalition of political support for the space station by suggesting it was capable of performing several different technical missions concurrently. Therefore when NASA was discussing the space station program it did so without discussing configurations or detailed technical ideas. NASA won support for the *idea* of the space station, but once this idea was approved, choosing a technical design to match all the desired capabilities proved to be more difficult than anticipated. When it was first approved, it was estimated that the station could be built for approximately $8 billion. NASA spent that much money on trade-off studies just to choose a design. The end result, according to McCurdy, is an ISS that is primarily a life sciences platform, which is not what it was initially intended for.

McCurdy discussed some current public opinion polls related to the space program. He said that approximately 30 percent of the public supports increased spending by NASA. This level of support is quite high for NASA, or for most programs, according to McCurdy. The space program is on the national agenda because of the *Columbia* accident, and 2004 is a presidential election year. These are signs that indicate the possibility of increased funding for a new project in the space program. Countering these forces is the historical fact that politicians are wary of making long-term policy commitments. For space, a long-term commitment is necessary, in particular if one considers the benefit a long-term commitment would have for guiding decisions about the space station and a successor to the space shuttle. Furthermore, long-term commitments help engineering decisions. McCurdy said that this moment in time is a great opportunity for the participants to influence the process as it deals with these various forces.

McCurdy closed his remarks by saying that the public and politicians are quick to embrace a vision, but they are not always willing to pay for it. He presented some public opinion polls that show support for more money going to the space program to improve our capabilities in low Earth orbit—support for replacing the shuttle, finishing the ISS, and still doing good science. All of these things cannot be accomplished without great resources, McCurdy said. Will the public support all of it? McCurdy said that remains to be seen.

Logsdon opened the discussion period by saying that this could be an historic time for the space program. The decision process that President Kennedy followed could be described by a model of rational choice. This is much different from the incremental approach described by McCurdy. Logsdon asked if the nation is in a position to make a rational decision about the space program. There will have to be winners and losers with rational choices. This is different from the incremental, coalition-building approach that NASA has previously followed because it means some people will be told "no." Is the political system ready to do that? There are other questions that Logsdon drew from his and McCurdy's presentations: Is human spaceflight as a symbol of strength and power a good enough reason to continue human spaceflight? Must we advance alternative technical or strategic justifications, when they may not withstand close scrutiny? Are human spaceflight and human exploration of space now part of the expected portfolio of U.S. activities? The first President Bush called it destiny. Is that enough? The remainder of the workshop, Logsdon suggested, should answer those questions.

In response to one question, Logsdon and McCurdy briefly discussed the different rationales for the space station besides national prestige. McCurdy argued that the potential commercial value of the space station was a bigger driver than anything else in the original decision to proceed with the station. Logsdon recalled a commercial by McDonnell Douglas in 1983—some kind of station seen in orbit, voices in the background speaking Russian, and a question appearing on the screen: "Shouldn't we be



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there, too?" Logsdon suggested that in 1983 the urge to compete with the Soviets was still very potent. The discussion about the space station continued with Radford Byerly basically agreeing with the difficulty of associating specific hardware and policy decisions and suggesting that a policy to build something may best be implemented in a way that lets you learn as you build. McCurdy said this reminded him of James Beggs's belief that you could build a space station the same way you buy cloth—by the yard.

Riccardo Giacconi asked whether it is the case that the policy environment forces NASA to choose poor technical designs for its programs. Giacconi said he understood that NASA needs consensus to get support, but it is not obliged to go too far to get that consensus—it is not forced to promise more than it can deliver. NASA chooses to make those promises on its own, and this is the fundamental problem. Giacconi said he believes this to be a failure of execution, not a failure of policy or politics. McCurdy replied by recalling an interview he had with former NASA Administrator James Fletcher, who indicated that perhaps the greatest mistake he, Fletcher, had ever made was not going to the White House, after the decision was made to build the space shuttle, and confess that in fact NASA could not build such a vehicle for the available funding. Logsdon followed up on this point by stating his belief that the space program has for so long been on such shaky political footing, that its leaders have refused to take the risk of being honest and saying, "We can't really do that." They do not want to test the hypothesis, according to Logsdon, that they can be honest about what could be done and risk losing political support.

Robert Richardson asked how much NASA needs its human program as a way to keep support alive for the remainder of its scientific programs. Both Logsdon and McCurdy agreed that NASA is very dependent on its human program. It was Logsdon's opinion that a discussion about the future of the civil space program really meant a discussion on the future of human exploration. While space science is strong, there has never been a decision at the level of the President on an issue of science, except in 1981, when there were some efforts by the Reagan Administration to cancel planetary exploration programs and Congress intervened to save them. Logsdon indicated that former NASA Administrator Daniel Goldin learned this the hard way. Goldin wanted to cut the station program when he got to NASA but realized that he could not, for fear of how it would hurt the agency. Logsdon admitted that this is not always a comforting realization for the science community. Robert Frosch supported Logsdon's comment in this regard. When Frosch was asked by the White House, in his capacity as NASA administrator, whether NASA should cancel the shuttle program, he realized he could not. If he did, "the whole thing comes down around it."

Lastly, SSB member Donald Ingber said that he was struck by what he felt was a lack of "positive spin" to our space program. By this he meant that NASA's manned spaceflight program provided an incredible opportunity to show the world how our nation can use its power in constructive ways, to collaborate and cooperate with the international community, and to explore a higher goal that can benefit all. Ingber noted that, at a time when other nations see only the intimidating aspects of our power, this type of constructive message could have a major positive impact on national security by facilitating international diplomacy and trust. McCurdy agreed, stating that even President Eisenhower believed that the first U.S. satellite should not be a military satellite. Logsdon felt that image and strength are important, but there should be a positive aspect to that visibility.



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# 4
# Rationales for the Space Program: Science, Technology, and Exploration

SSB member and astronomer Megan Urry of Yale University served as moderator for the panel, which was composed of planetary scientist and former senior NASA executive Wesley Huntress of the Carnegie Institution of Washington; astronomer Riccardo Giacconi, a research professor at Johns Hopkins University and president of Associated Universities, Inc.; planetary scientist and former astronaut Thomas Jones; microbiologist Mary Jane Osborn of the University of Connecticut; and ASEB member and aerospace engineering professor Dava Newman of MIT. Panelists were asked to explore the following questions in their remarks:

- What are the contributions of science and exploration to broader national interests?
- Is the new knowledge created by science the ultimate objective of the U.S. space program, or is it a by-product of space activities carried out for other reasons?
- What are the contributions of humans in space as researchers, as explorers, as motivators?

Giacconi opened by saying that it was important to be clear about the long-term goals of the space program, which he cited as (1) the pursuit of science and (2) human exploration. He suggested that the rationale for the two programs should be separate and that one cannot justify the human exploration program because of science, or vice versa. Efforts to justify the ISS on the basis of science are not productive. Giacconi argued that the ISS should focus on being an enabling technology testbed and human physiology laboratory in support of long-term human space exploration. He added that our space assets should be considered capital investments—to be serviced and built upon (as has been the case with the Hubble Space Telescope), not just thrown away. This provides a rationale for human spaceflight in addition to exploration.

Giacconi stated that the science program is going well, does not need additional justification because it stands on its own merits, and is working almost as an independent agency at NASA.[1] He disagreed that science should be a fixed part of NASA's budget; it should compete, as any other discipline must. However, on the issue of human exploration, Giacconi noted that the problems are much greater than for the science programs, and the lack of long-term goals for human exploration has been disastrous. He argued that the goal of the human exploration program should be a permanent colony at Mars and that technical and fiscal planning toward this goal should start now. The ISS should be used to support that goal. The drive to explore is human, he noted; exploration is a general impulse of human nature.

Osborn discussed the life sciences program, a small component of NASA's science program, which includes research on fundamental biological processes that are dependent on gravity for development or function or both, those aspects of physiology and behavior that are affected by microgravity environments, and medical and applied biosciences that are relevant either to flight safety or to long-term human survival and performance in space. She said these sciences should have a high priority in the life sciences program if there is a true commitment to human exploration of space.

Osborn reflected that, at present, the U.S. commitment to human spaceflight is fragile and that enthusiasm has steadily eroded since the Moon landings. She noted that the ISS was in a perilous state before the *Columbia* tragedy, and given federal deficit projections there will be limited funds to rescue the ISS as a meaningful platform for high-quality life sciences research. It is difficult to argue that life sciences should have a high priority in the current NASA portfolio, because no highly visible past successes or breakthroughs can be claimed. Some of the choices that led to life sciences experiments in the past were not well considered, and in response the community deemed some experiments trivial.

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[1] See Giacconi's contributed abstract, "On the Future of the Space Program," Appendix E.



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NASA's biomedical research will not solve terrestrial problems of aging or cancer, but the NASA program is essential to understanding astronaut performance in space and the effects of the space environment on human health.

Osborn asserted that if there is no commitment to long-duration human spaceflight, the rationale for NASA's biomedical program largely evaporates. There are a limited set of physical and biological processes that are dependent on gravity—plant gravitropism and vestibular physiology, for example. The mechanisms for such processes are not well understood and can only be studied in space where gravity is an independent variable. Biological experiments often require intervention by humans, hence the need for the ISS and the need for trained human investigators. But if the ISS is maintained as a platform for research on long-duration spaceflight and there is a true commitment to human exploration of space, then research to ensure the health and performance of astronauts becomes relevant as a major concern.

Osborn added that it is unclear whether the space station will be completed to the point that it can fairly be regarded as a good laboratory facility. Even before the *Columbia* accident, declines in the projected capabilities of facilities on the ISS had led to loss of interest by the life sciences community. Nevertheless, while the current outlook is bleak, the role of the space station in preparing for future human space exploration is very important.

Huntress began by saying that we explore space with humans for psycho-social reasons that can't be quantified. It's a discretionary activity for government, but the benefits must be powerful or we would not have invested. We have an imperative to explore; it's a survival instinct. Moreover, he argued that human exploration is part of our culture, part of who we are as a nation. We explore space because we choose to do so, because we have a manifest destiny in space. The economic benefits of exploration are unpredictable, but they always follow.

Huntress remarked that science is the principal product of the robotic program, which has a solid basis of support inside and outside the Washington beltway, and referred to the inspiration and productivity of the space science program in his written abstract.[2] However, he noted that decisions on the human exploration program will be made more on societal than on scientific grounds.[3] When a decision is made to continue human exploration beyond low Earth orbit it will provide an opportunity for science, and that science should be the force in defining the goals for human exploration. He reflected that Apollo accomplished its real (geopolitical) goals and that the nation then moved on to other priorities. The ISS and the shuttle are products of NASA's attempting over the decades to preserve the Apollo-like era of human spaceflight, an era that has already passed. The problems we are experiencing are not with human spaceflight but with this kind of human spaceflight. The ISS is not the kind of platform it was supposed to be for missions beyond low Earth orbit, and the shuttle is not the cheap, low-risk transportation system it was supposed to be.

We've been burdened with a history of misguided policy decisions, the legacy of which is not easily or quickly undone, according to Huntress. The legacy of the *Columbia* accident should be to create a new pathway and a sense of purpose for human spaceflight. We should create a more robust transportation system for astronauts and a more rewarding program of exploration for these heroes. If space explorers are to risk their lives, it should be for extraordinary reasons and challenging ones such as exploration of the Moon, Mars, and asteroids, or constructing and servicing space telescopes, and not for making 90-minute trips around Earth. He asserted that the point of leaving home is to go somewhere, and not to endlessly circle the block, which is what we've been doing for 30 years. Robotic and human exploration programs have always coexisted and cooperated to some extent. Humans provide the public with a sense of human destiny in space. Robotic exploration is an extension of the human experience. Huntress said that we always seem to need heroes, and astronauts are heroes of this age. Sooner or later we need a clear destination for human exploration or it simply will not survive. This effort does not have to be funded

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[2] See Huntress's contributed abstract, "On Future National Space Policy," Appendix E.
[3] This point is echoed in Space Studies Board, National Research Council, *The Human Exploration of Space*, National Academy Press, Washington, D.C., 1997.



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like Apollo, Huntress said; it can proceed at a much steadier pace. He suggested that the nation adopt a long-term policy—to establish a permanent human presence in the solar system beyond low Earth orbit.

Newman stated that NASA's mandate is exploration, and she focused her remarks on exploration and the need for humans in space. She highlighted that exploration is synonymous with education, inspiration, motivation, excitement, dreams, and creativity, and that every one of us has been touched by space exploration. She noted that future generations are the heirs of whatever short-term or long-term policy is set. She argued that a national space policy should include education starting with K-12 and extending beyond, and should include a commitment to develop the future workforce. Students are most interested in solving the challenges that haven't been solved yet.

Newman supported the role of both humans and robots in space. Robots enable exploration and humans enable serendipity, she said. She argued that it's senseless to pit humans against robots, and that we need to find the right balance and combination between the two.[4]

Newman also referred to the risk of human spaceflight and noted that risk should be reduced if possible. However, given the high risk for missions beyond low Earth orbit, she argued that we need to articulate the message of our goal in space and then accept the risk. The acceptance of risk, however, is dependent on educating the public, she noted.

Newman suggested that the ISS is best used as a testbed and for research into the physiological effects of spaceflight, and that science on the space station should be focused on long-duration performance. She also said that the United States should be a leader in the commitment to peaceful cooperation in space, and that future plans for human exploration should involve international cooperation.

Jones discussed the contributions of humans as explorers and motivators. "I'm a successfully flown and returned space life sciences experiment," he quipped. He said that we, as a nation, have to confront the ethics of sending our astronauts into space. What mission justifies the risk we are asking them to take? He stated that the goal must be commensurate with the risk we ask our explorers to take.

Jones discussed four unique characteristics of humans as explorers, all crucial to the future of the space program:

- *Experience*. Only humans are capable of applying insight, understanding our questions about the universe, and acting/reacting on human time scales. Involving humans is also necessary for getting results politically.
- *Flexibility.* Humans are good problem solvers and are innately flexible. The detailed studies that we want to conduct on asteroids, the Moon, and Mars can only be done by humans. Human skills include problem recognition, prioritization of problems, exercise of judgment, and mechanical skills. We can look at how humans have salvaged situations in space (e.g., satellite repairs, Hubble Space Telescope servicing, and intervention to replace critical components). In comparison, the robotic Galileo mission lost its high-gain antenna and couldn't be helped because it wasn't accessible to humans.
- *Confidence.* Humans substantially increase the odds of mission success. When we want to see the results within the span of a human career, or if we must succeed in a space endeavor (e.g., a detailed search for life on Mars, or a crucial asteroid deflection), human flexibility and prompt decision making at the scene are needed.
- *Communication*. Only humans can convey the experience of being in space to humans on Earth. We have an innate curiosity that can't be satisfied by data and images. We are not satisfied with our knowledge of a place unless we hear from a human who's been there and can then experience it vicariously. Private space travel will attract a market for these reasons.

Jones noted that Americans always have had a sense of the importance of pioneering the frontier. When Jefferson dispatched Lewis and Clark to the unknown West, those captains were fully aware of the

[4] Mankins, J.C., "The Exploration and Development of Space: The International Space Station and Beyond," from *Beyond the ISS: The Future of Human Spaceflight*, Advanced Programs Office, NASA, Washington, D.C.



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importance of their mission to America's future. For 200 years, Americans have identified with that spirit of pioneering, even though relatively few played an active role in the Westward expansion. Space exploration builds on that American characteristic and taps into our society's desire to find success and opportunity on this century's frontier.

Session moderator Megan Urry opened the discussion by noting that she had heard a unified response among the panelists that the science done in space has been extremely successful and has allowed many people to wonder about the universe. Should science and exploration be separate? She summarized that panelists seemed to think that science should not have to justify exploration and that exploration is a cultural endeavor. She also asked the panel to consider the question of what is acceptable risk. What activities make that risk worthwhile?

The participants discussed a human's ability to survive long-duration space missions and the research necessary to enable a long-term presence in space. SSB member Harry McSween noted that there is an unspoken assumption for a grander vision of humans beyond low Earth orbit, which is that the medical problems can be solved, although we don't yet know that this is not an insurmountable obstacle. NASA ought to make this biomedical research a higher priority than it is. Osborn stated that there can be effective countermeasures for long-duration exposure to microgravity. These are physiological problems that can be understood and addressed. However, physiological or pharmacological interventions that can take care of severe exposure to radiation are unlikely. How to protect astronauts from radiation over long periods of time is a hardware issue. She said that we should follow a mix of biomedical research, most of which should be ground based, with limited flight experiments to test the hypotheses and proposed countermeasure activities.

Giacconi argued that the focus of study should be on fractional gravity (artificial gravity) rather than microgravity, and Osborn agreed. She said that we need the experiments to know what factional gravity is needed, however. Richardson said the importance of studying gravity as an independent variable has to be emphasized. He felt that many early experiments in life sciences have had peculiar and hard-to-believe results, and unless one can turn gravity on and off, research on the effects of gravity is absolutely critical. The ISS core-complete design does not include the capability to study gravity as an independent variable because the design does not include a variable-gravity centrifuge. Osborn added that the biomedical science that should be done on the ISS is clear, but the ISS has not had the required facilities or crew time or expertise to conduct those experiments. She felt that 95 percent of the research that has to be done can be done on the ground. To prepare for human exploration beyond low Earth orbit, the ISS is inadequate as it now exists, and NRC reports specify these points.[5] Giacconi suggested that we need more emphasis on technology development that could be used in turn for assembly, servicing, and robot-to-robot work and that could strengthen the ISS capability. The public would not go along with abandoning the ISS. Ingber stressed the need to prioritize what has to be done and to do the science that meets priorities within the necessary time frame.

In response to the moderator's earlier question, many participants voiced agreement that human exploration cannot be justified on purely scientific grounds, but the goals of human exploration should include attendant scientific goals so as to gain the maximum return. Frosch took issue with the division of science and exploration and argued that exploration is a form of science; it is science at an early stage. He referred to the oceanographic community and noted that scientists want to dive on the *Alvin* and look at the deep oceans, because they see things and get from the experience something that they do not get from remote presentations. "Do we really want dumb robots telling us the pre-history of Mars?" Frosch asked.

Participants also discussed the issue of risk tolerance in the program. Fisk remarked that problems with the human exploration program imply risks and humans can deal with risks. Yet, he noted, we have

[5] See Space Studies Board, National Research Council, *A Strategy for Research in Space Biology and Medicine in the New Century*, National Academy Press, Washington, D.C., 1998; Space Studies Board, National Research Council, *Factors Affecting the Utilization of the International Space Station for Research in the Biological and Physical Sciences,* National Academies Press, 2002.



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a space program and a public that are risk-averse. We have lost many more people in Afghanistan and Iraq, but the loss of astronauts made a huge impact. How do we take a culture that is risk-averse and create a space program that understands risks, accepts risks, and has a role for humans? Huntress noted that if the human spaceflight program had a clear goal and destination, then there would be more tolerance for risk on the part of the public. Huntress stated that the shuttle is too risky to continue using other than to travel to the ISS. We need to reinvent the system for crew and for cargo transport to the ISS and separate the two. For the crew part, travel should be reliable, low cost, and focus on the safety of the crew. Jones stated that beyond the ISS we need a versatile platform that allows a variety of missions. Regarding the shuttle, SSB member and former astronaut Tamara Jernigan said that even if the risks were greater, astronauts would still fly. Risk is justifiable for those who commit to flying on the shuttle. Exploration, by definition, is a dangerous venture that requires risk taking. Thus, the goal is not to eliminate risk, but rather to minimize risk that is due to poor management or lack of rigor, and hence that is both easily avoidable and unacceptable.



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# 5
# Rationales for the Space Program: National Security, Commerce, and International Cooperation

The session was moderated by SSB member Ralph Jacobson, a retired USAF general and president emeritus of the Charles Stark Draper Laboratories. The panelists were ASEB member Donald Cromer, former president of Hughes Space and Communications and a former USAF Lt. General; Norman Neureiter, former science advisor to the Secretary of State and former vice president of Texas Instruments Asia; and James R. Thompson, vice chairman of Orbital Sciences Corp. The panelists for this session were asked to address one or all of the following questions:

- How should one weigh the interactions between national security, military, and civilian space efforts?
- Will space become an economic center of gravity?
- What are the contributions of space activities to U.S. foreign policy objectives?

Cromer stated that as he sees it, the general public view is that the space program equals NASA. However, commercial and defense spending on space is greater than spending for NASA. Regarding the interactions between the different sectors involved in space activities, he believes that the *Final Report of the Commission on the Future of the United States Aerospace Industry* articulates some of them.[1] In particular he noted the report's commentary on the growing dependence of our military on space assets and the value of space assets to national security. These have to be regarded as valuable pieces of a larger, broader space program.

Cromer pointed to the need for an industrial base as the aspect that perhaps unites the national security, military, and civil sectors the most. Another area where there is overlap is in technology development. Developments that are sometimes led by the commercial area will find their way into military systems, and vice versa. On-board computing for communication satellites is an example of this kind of synergy. Joint development leads to significantly greater generational improvement. There are other synergies in terms of the application of space technologies—Global Positioning System (GPS), remote sensing, weather, and launch capabilities.

Regarding the military's dependence on communication satellites, Cromer stated that more than 80 percent of the military's communications in and out of both the Desert Storm and Iraqi Freedom theaters involved commercial satellite assets, not military systems. It was his opinion that the U.S. military needs to reverse the way it uses commercial systems. The military should utilize commercial assets during peacetime and count on military systems for the surge in capability that is needed during combat. According to Cromer, it is not clear that the Department of Defense's mobile telephone requirements will be met in the future without better planning and development.

In Cromer's opinion, all of these issues—joint technology development, taking advantage of synergies, and better planning and development by the military—are dependent on the availability of a skilled industrial base.

Cromer, addressing whether space will become an economic center of gravity, suggested that in the broadest sense it already is. He pointed to the applications and impact of satellite weather data; the use of GPS for timing and location in so many industries, even agriculture; direct-to-home TV; and soon, direct-to-home Internet. In a narrower sense, commercial space is emerging. Satellite services are making money, but satellite manufacturing companies are having a tough time. Cromer felt that there will be

[1] Commission on the Future of the United States Aerospace Industry, *Final Report of the Commission on the Future of the United States Aerospace Industry*, Arlington, Virginia, 2002.



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growth in commercial space. In the past 6 years, the money spent for satellite-based services increased 3.5-fold, and there will clearly be an increase in the demand for satellite services. The market for these services will be dominated by North America and Europe, which will probably constitute approximately 70 percent of the total market.

Cromer saw the space program's contribution to foreign policy as a leveraging tool. Success in commercial space is important in this regard, and this is where the International Traffic in Arms Regulations (ITAR) are relevant to this discussion.[2] Having commercial satellites on the munitions control list is not the best policy. Cromer said that the U.S. market share for commercial satellite sales went from more than 70 percent to less than 35 percent between 1999 and 2003. The impact of ITAR on satellite sales was illustrated even more sharply recently when Arabsat gave a $300 million contract to EADS instead of to Lockheed Martin, saying publicly that it was because of U.S. export regulations. Similarly, Cromer stated that although they formerly looked to U.S. companies, European satellite manufacturers are now looking to other European companies for components, because of difficulties with export controls. The worst part of it, according to Cromer, is that there is no evidence that U.S. export controls ultimately help national security. There are so many other providers of the same technology that those who seek it can find it elsewhere fairly easily. This has hurt the U.S. industrial base.

Neureiter addressed the foreign policy dimensions of the space program. NASA was established as a civil space organization on purpose, leaving the military to pursue its space needs separately. International cooperation was to be part of NASA's job—cooperation under NASA leadership.[3] A 1999 National Research Council report identified the many ways in which the U.S. expertise in science and technology can help the federal government achieve its foreign policy and public diplomacy goals.[4] In particular, the report cited 16 foreign policy goals articulated by the Department of State,[5] indicating how 13 of these goals encompass considerations of science, technology, or health. Implicit in the 16 goals is the broad objective of contributing to the peace and prosperity of the world's nations. Pursuing cooperative efforts in science and technology, according to Neureiter, can help do just that.

Neureiter discussed how after World War II there was a desire in the United States to do good things for people and the world, which led to cooperative efforts to advance, for example, the peaceful uses of nuclear technology. The Apollo program was undertaken by the United States as an image maker to demonstrate U.S. superiority in space. It made U.S. astronauts heroes, and in later space activities, other nations' astronauts participating in U.S. programs also became national heroes in their countries. Good space cooperation is good diplomacy. In Neureiter's opinion, space cooperation can be a powerful instrument for building better relationships with other countries, sometimes even with ones with which relations are not so good. That was the motivation behind the initial space cooperation with the USSR in the 1970s. Polls show that Arab countries have great admiration for U.S. S&T. One might ask if any aspect of space cooperation with those countries might offer unique opportunities in the area of public diplomacy.

Neureiter indicated that two issues currently dominate U.S. foreign policy, both related to the war on terrorism. One is nonproliferation of weapons of mass destruction, and the other is homeland security. Certainly, space cooperation carries a proliferation risk, as it may be connected with delivery systems. Neureiter said that all U.S. foreign policy decisions or proposed cooperative programs will be carefully screened for proliferation risks. Regarding the impact of nonproliferation concerns as manifested in

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[2] Code of Federal Regulations, International Traffic in Arms Regulations (ITAR), Title 22, Foreign Relations, Subchapter M, Parts 120-130, Revised, April 1, 2003.
[3] Public Law Number 85-568, as amended, the National Aeronautics and Space Act, 1958.
[4] National Research Council, *The Pervasive Role of Science, Technology, and Health in Foreign Policy: Imperatives for the Department of State*, National Academy Press, Washington, D.C., 1999.
[5] "The United States Strategic Plan for International Affairs, First Revision," released by the Office of Resources, Plans, and Policy, U.S. Department of State, Washington D.C., February 1999. Available at <http://www.state.gov/www/global/general_foreign_policy/99_stratplan_toc.html>.



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ITAR-based export controls, Neureiter said that recent studies have concluded that these controls have effectively given our foreign competitors a captive market abroad. Another issue at times impeding cooperation is linkage, where, for example, to respond to a country for actions the United States does not like, Congress may legislate a broad sanction that also can affect only remotely related fields. Once legislation is in place, changing it is very difficult. The Iran Nonproliferation Act,[6] for instance, places significant constraints on our space cooperation with Russia, which, in a manner certainly unanticipated earlier, is having an impact on work on the space station after the loss of the *Columbia* shuttle.

Neureiter cited a recent major conference on U.S.-China affairs, in which senior U.S. foreign policy figures referred to U.S. ties with China as America's most important bilateral relationship in the coming years. Since the issuance of the Cox Report in 1998,[7] concerns over proliferation and loss of critical technology have sharply limited space cooperation with China and have increased congressional scrutiny of the broader cooperative relationship in S&T with China. With its recent launch of a man in space and ambitious plans for a manned space program, China will be presenting itself as a model of technical prowess for the developing world and will continue to promote its space program. Another important U.S. bilateral relationship is with India, which has expressed great interest in closer cooperation in space endeavors. That relationship is also limited because of proliferation concerns, but to a lesser extent than in the case of China.

When it comes to international, cooperative, "big technology" programs Neureiter said that the United States has a mixed reputation in terms of reliability, cancellation of project funding, early withdrawal, and so on. The ISS is a big technology program with many international partners who have invested heavily in it for several years. It had already survived one crisis involving a huge cost overrun. With the loss of *Columbia*, some critics have talked about killing the ISS or even stopping manned spaceflight altogether. Despite what may be shortcomings of the ISS, the United States must not forget its partners, and any major decision should involve them. Neureiter felt that canceling the ISS unilaterally now would further contribute to the image of the United States as an unreliable partner and also be a public diplomacy failure and a huge embarrassment on the world stage, especially in view of China's success. This example could also jeopardize other nations' participation in future big S&T projects, such as the next particle accelerator. Neureiter concluded that the best solution in terms of the image of U.S. technological leadership and public diplomacy would be to salvage the ISS and drive forward. If further analysis yields the opposite conclusion, he said, then we must work with our partners on the final resolution. Finally, he felt strongly that the United States cannot at this stage give up on manned spaceflight altogether, regardless of decisions on specific programs. It would appear as a major retreat from a position of unquestioned global technology leadership today.

Thompson started his remarks by noting his sense that some conclusions so far included a need to phase out the space shuttle, improve the capabilities of the ISS to do science, and not limit the other science programs at NASA. He said that all of this would cost a great deal of money and that we should be careful not to try to cram 10 pounds into a 5-pound bag. The rest of his remarks, Thompson said, would focus on the manned program, as he regarded the science programs as excellent.

Thompson said that the shuttle is a good engineering feat, but it falls short on its cost estimates. The shuttle, he said, has been beaten up by the way that it has been used operationally. He agreed that it should not be extended for too long, but that it will take at least 6 to 10 years, at a minimum, to meet the needs of the ISS. He said the worst thing that could be done to the shuttle would be to "phase it out" and

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[6] The Iran Nonproliferation Act of 2000, Public Law 106-178.

[7] *U.S. National Security and Military/Commercial Concerns with the People's Republic of China*, report of the Select Committee on U.S. National Security and Military/Commercial Concerns with the People's Republic of China, submitted by Mr. Cox of California, chairman; May 25, 1999—declassified in part, U.S. Government Printing Office, 1999.



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not fund it—that would do more to hurt the ISS than help it. The problem with the shuttle is with the operators, not with the vehicle itself, Thompson summarized.

Thompson said he believed that the United States could have built the ISS incrementally, but the process got out of hand and the program was too hard to control as it was implemented. The country should examine how to fix the ISS, but not kill it. That, plus not handling the shuttle appropriately, could hurt all future efforts.

Thompson noted that he thinks there is a desire to rush—to get back to business. The ISS isn't doing science, the shuttle is down, and people are anxious. Thompson indicated that we should take time to be smart about how we get back to flight. He said that Mars is a good long-term goal, but it cannot be accomplished now because we do not have the technology, in particular the propulsion technology. Furthermore Thompson indicated that the budget situation is too hard to predict—there are deficits, the war on terror, and Iraq to be dealt with. It seems too difficult to determine how the space program can compete as a priority.

Thompson agreed with Cromer about the fact that all the sectors—national security, military, and civil—benefit from technology development, and he said he believed that NASA is the best place to do that kind of technology development. Thompson noted that aeronautical research at NASA has been underfunded and ignored over the last decade. It should get its share, and he indicated that hypersonic technologies are an example of technology development that could benefit all the sectors. Thompson also said that he thinks NASA should not be operating a system for the hundredth time, so he agreed with transferring the shuttle to private hands for its operation. In this regard he feels that the contractors did not step up to their responsibilities. Similarly, NASA should not operate the ISS in the long term. NASA is not very good at operating big systems. NASA has to be a technology driver, making new technology instead of operating old technology.

Moderator Ralph Jacobson opened the discussion by indicating that, in his opinion, policy for the various sectors of space activity gets made on the basis of their *raison d'etre*. The National Reconnaissance Office (NRO) and other military space programs have solid and easily identifiable reasons for being—the defense of this republic. In defense, there is so much competition for resources that if a program or a technology asset survives at all, that is a commentary on its support and value. In the commercial world, the market is the primary driver, the primary reason for being. However, policy can affect our nation's strength in the market, and our current ITAR policy hurts our position in the market.

Jacobson said that the civil space program's reason for being is difficult to articulate. If one were forced to choose between the civil space program's science missions and the missions of the NRO, the NRO would win. Human spaceflight or human exploration can be justified in terms of visible evidence of technical prowess, but the recent record is poor and this workshop has shown how that can be harmful for the program. This difficulty in justification needs to be addressed.

Fisk started the question period off by asking whether or not the United States has demonstrated its technological prowess in so many other ways over the past 10 years that the space program doesn't have to do that anymore. Neureiter said that he thinks that the space program is not just about demonstrating. It is about building a global fabric of relationships that will survive no matter what bad things might happen. Neureiter said that in parts of the world the United States is feared for its power and that others are concerned with how we use our power. Cooperation in our civil space programs helps allay those concerns.

Jernigan followed up by asking if the space program and cooperation in human spaceflight decrease the probability of war. Neureiter said that he thinks they do, in that they can be tools to build relationships with those who agree with the United States and also to reach out to start the foundation of a more stable relationship with those who may not so completely agree with us on other issues. It's a way to engage, and Neureiter believes engagement helps. Cooperation in space programs may be limited in what it can do, but it is important to try. Citing China as an example, Cromer agreed and said that through space we can make friends and build trust.



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Following this remark on China, SSB member James Burch asked, "If China lands on the Moon in 10 years, should the United States be there to greet them?" All of the panelists agreed that going to the Moon for the sake of beating the Chinese in another space race was not the right thing to do. Frosch discussed our past history of cooperation. The United States would make its own decisions and then try to convince its international partners to agree. In the future, Frosch said, we need to turn to the international community, lay out the problems and the potential solutions, and figure them out together. European Space Science Committee Chair Gerhard Haerendel agreed, saying that future endeavors must be viewed as truly global from the outset.

Byerly said that the United States seems to have only two choices, as the human spaceflight program stands now. Either turn off the current programs now and start over, or run them forever. Obviously though, we cannot do either, so how do we transition to a new state? What should be the criteria? Logsdon followed up on Byerly's comment by suggesting that perhaps a new goal or new destination can serve as an exit strategy to get away from the current programs—the shuttle and the ISS. The United States needs to have a kind of roadmap from where we are to where we want to go. As Logsdon put it to the audience, Can we use the coalition in place with the ISS as a planning basis for future cooperation? He said he thinks a potential problem will be resources: "Can you get 100 percent of the costs if the United States doesn't step up for 75 percent of the funding?" He thinks not. Giacconi said he can imagine an international human exploration program, but he cannot really see it happening because of space's links to defense.

Cromer ended the session by indicating that whatever choices are made, the nation needs to see "restructuring" or else nothing will be fixed. This includes restructuring NASA, restructuring funding mechanisms, and restructuring the space program's rationale.



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# 6
# Guiding Principles of a 21st-Century Space Policy

The panel was moderated by SSB member and former Aerospace Corporation executive George Paulikas. The panelists included Albert Wheelon, former president and CEO of Hughes Aircraft Company; Noel Hinners, a planetary scientist and former senior industry and NASA executive; Todd La Porte, a political scientist from the University of California at Berkeley; and Robert Richardson, a physicist and university administrator from Cornell University. Panelists were asked to address the following questions:

- What principles should apply for setting goals and priorities and defining balance?
- What are the implications for defining institutional roles and responsibilities and other organizational factors?

Wheelon presented a framework for the total national space effort comprising five different U.S. space programs, all of which have different needs, masters, purposes, and funding sources, though they share the same technology base and rockets. The five programs include (1) the National Reconnaissance Program with an estimated $8 billion annual budget,[1] (2) the military space program with an estimated $8.5 billion budget, (3) the commercial space program with an estimated $7 billion to $10 billion, (4) the NASA unmanned space program (Earth and space science) estimated at $5 billion, and (5) the manned space program estimated at $7 billion. He noted that it is interesting to see that all five are of similar magnitude.

1. *National Reconnaissance Program*. Wheelon said that the National Reconnaissance Program (NRP) was President Eisenhower's first response to Sputnik. The CORONA program, which conducted reconnaissance of the USSR and China, was authorized 5 months after the Sputnik launch and received a very high priority in several administrations. The first CORONA flight occurred, and failed, 11 months after the program's initiation. There were 13 successive failures, but each failure was discussed with Eisenhower and the program went forward nonetheless. The first success, in August 1960, occurred 18 months after the decision to proceed, and Wheelon said that we got more film back than from all of the U-2 flights put together. CORONA conducted 145 flights over the next 12 years, and its reentry capsule provided key technology for the Mercury missions. Wheelon noted that the CORONA program had the president's immediate interest from the very beginning and that all subsequent presidents stayed personally involved throughout the program's history. CORONA was succeeded by two second-generation systems. He reported that a near-real-time system, which does not require film recovery, was first launched in 1976, and we're still using it. Scientists and engineers from the civil space community were involved in the NRP. They pressed Eisenhower to initiate CORONA, and they helped guide the reconnaissance programs. The National Academies have never played an organizing role in getting these NRP advisors together, but Academy people have been involved.

The NRP, which enjoyed unusual secrecy and flexibility, had linkages with the NASA civil program in several ways. The Hubble Space Telescope, for example, was derived from one of the NRP second-generation programs. The Manned Orbiting Laboratory (MOL) was another example. Its principal job would have been to enable manned supervision of reconnaissance and surveillance of Earth. The MOL was abandoned, however, because engineers determined that astronauts' movements would cause image blurring, Wheelon recounted. Another cross-coupling between the NRP and NASA was the shuttle. The shuttle's cargo bay size was designed to accommodate NRP's largest payload, and the NRP placed specifications on payload weight.

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[1] Budget data provided for the five programs are approximate figures for Fiscal Year 2003.



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Wheelon believes that, at present, the NRP is having a midlife crisis. Its mission has changed—the program was designed to go after Russia and China but the problems are different today. The organization's old age and transition to a public, partially unclassified existence have contributed to the problem.

2. *Military program*. Wheelon reflected that prior to Sputnik, the military space program didn't have enough emphasis or enough priority to get going. Sputnik changed that. Since then one can point to major successes. For example GPS, which was initially developed as a military asset, is a major success and in its broadest context is probably more important than communication satellites. Second, missile-warning satellites in synchronous orbit, which enable us to detect missile launches within a 100-mile range and within a minute of launch, are an important stabilizing factor.

Wheelon reflected that the National Academies have not played a strong role in advising the Air Force but could play a stronger role in the future. He commented that the military program is committed to expendable launch vehicles (ELVs), and the military is not interested in having manned missions, given their cost and the uncertainty in launches. He mentioned that the operators of military satellites were shaken after the *Challenger* accident, because they had been told to fly military payloads solely on the shuttle.

3. *Commercial program*. Wheelon noted that the commercial space program is based largely on communication satellites. The Comsat Act of 1962 established Comsat and Intelsat, which was an important international activity. They adopted the synchronous solution, and that led to a flowering of communications satellites, operators, and countries coming into the act and to the development of global systems. From 1970 until mid-1996, the business flourished and there was lots of private capital going into the R&D. Most of the development work in communications satellites was paid for by Intelsat. Wheelon noted that NASA played an important early role but dropped out later. All of the technological developments in communications satellites have come about from private investment or, in some cases, military investment. He remarked that communication satellites are in a difficult state. Deregulation undermined Intelsat's monopoly, and it is no longer in a position to support spacecraft and technology as it once did. There have been such large investments in fiber optics that overcapacity has developed, which has driven the price of communications services down to the point at which it has had a serious impact on the business. There were other questionable investments as well, such as Motorola's investment in Iridium, which has probably lost $6 billion to $7 billion in actual investments and guarantees. There is excess spacecraft capability, both in terms of satellites built and the capabilities to build them. These decisions were driven by market forces and competition for other ways of doing the job, not by space policy. The people who make those decisions are MBAs, not engineers, and they make decisions based on economic considerations.

4. *Civil unmanned program*. Wheelon remarked that the unmanned space program is wonderful but has been a poor cousin at NASA. Almost all of the program relies on robotic spacecraft. The Hubble Space Telescope was designed to be serviced by astronauts, but that approach was a conscious choice. NRP launches new satellites to replace or upgrade its capability rather than servicing existing satellites. The cost for servicing and for launching replacement satellites is about the same, he said.

5. *Civil manned program*. With respect to the manned space program, Wheelon commented that the Mercury and Gemini programs represented a quick response to the challenge posed by the Soviet launch of Sputnik. Apollo met its goals and reasserted the U.S. ability to demonstrate technological prowess. Today, there is little need for the space program to demonstrate U.S. advanced technology, considering the successes, for instance, of the United States in personal computers and biotechnology.

Wheelon said that after Apollo a policy turning point came when NASA sought to make the shuttle the centerpiece for all U.S. launches. It aggressively sought a monopoly on all launches of U.S. spacecraft, and to that end designed the shuttle to meet everyone's requirements. To enforce this monopoly, NASA began closing the production lines of Delta, Atlas, and Titan in 1984. NRO invested $3 billion to create a shuttle launch site at Vandenberg Air Force Base to handle missions with military payloads. Having humans in the loop increased the costs to military users. Wheelon mentioned that since



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most national security missions were not suited to low Earth orbit, an inertial upper stage (IUS) had to be developed. The IUS had to meet all of the mission requirements in DOD. It started at an estimated $2 million a shot and ultimately soared to $80 million a shot. That's what happens when you build an all-purpose machine, he said. When *Challenger* exploded on January 28, 1986, so did the policy of putting all of our eggs in one basket. Wheelon noted that commercial customers for the shuttle were dropped, as were military payloads. NASA was left with a machine that could do all things, but with no customers save itself. The ISS became crucial to the shuttle's reason for being and for the manned program.

In looking to the future, Wheelon said that if it is necessary to support the ISS, it can be done without the shuttle. We can carry supplies to the ISS with expendable launch vehicles and rendezvous modules. Astronauts can be ferried in crew capsules like Soyuz with a few man-rated rockets, he said. How do we implement such a scenario? Wheelon argued that a substitute for the shuttle would not require much new technology. There are symmetrical reentry vehicles that do not require reorienting, and we have ablation technology well developed. He asserted that if the United States wants a challenging and exciting program, the shuttle and the ISS are not it. He said that he believes our country will respond to another grand challenge, though he was not sure when this challenge will occur. What might be a grand challenge? Wheelon noted that he was excited about going to Mars or its moons and even more excited about going to the moons of Jupiter. These missions would require assembly of transfer vehicles in Earth orbit as well as new types of propulsion vehicles. He urged the National Academies to consider such grand challenges and not be consumed in simply fine-tuning this exciting mix.

Hinners opened his remarks by stating that the challenge ahead is to "change the content of this room." He proposed that we need to get the youth back into leadership positions, noting that the senior players in the space community were leaving a vacuum in their wake.

In considering the human spaceflight program, Hinners asserted that NASA must work harder at integrating humans and robotics. The optimization of achievements can be better accomplished if we can marry the two. He said that NASA should invest in a firmer role for robotic, software, and information technologies in its manned space centers. Hinners supported the idea of an exit strategy for the ISS. The sole focus of the ISS should be to do biomedical, physiological, and psychological studies in support of future long-duration human exploration beyond low Earth orbit. He commented that we should do this research, and then "its job is done." He also noted that we have not done a good job collectively with international partners and that we need a more effective way to conduct such partnerships at the beginning rather than after programs have been defined.

Richardson said that his remarks would focus on the insights acquired through his experience on the ISS Management and Cost Evaluation (IMCE) Task Force.[2] He commented that his assessment of the scientific potential for the ISS, in his discipline, was that no transformational physics could be done there.

Richardson noted that there is no incentive for managers of the ISS to do anything other than the ISS, and this presents a serious disincentive for finishing the program. He mentioned that too many promises of what the ISS would do had been made to too many people. The program became completely unfocused. Richardson reported that there are 3000 people required to support a 3- to 7-person crew on the ISS, and this count does not include those needed to support the shuttle. Many of the ISS's systems depend on 1980s technology and designs, including, for example, IBM 486 computer systems.

The IMCE task force concluded that the highest priority of the ISS should be to focus on problems associated with long-duration human spaceflight. The variable-gravity research centrifuge is mandatory for this work, Richardson said. Richardson also referred to the problems of sustaining a long-term human presence in space, including exposure to radiation, maintaining a food supply, and controlling disease.

Richardson proposed a set of principles for setting goals and priorities and for defining balance in the space program, which should include the following:

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[2] Report by the International Space Station (ISS) Management and Cost Evaluation (IMCE) Task Force to the NASA Advisory Council, November 2001. Available at <http://history.nasa.gov/youngrep.pdf>; accessed December 9, 2003.



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- This will be a political decision, not a scientific one.
- A clear statement of purpose is needed, and so is an honest evaluation of whether it can be met.
- Defining the balance in institutional roles and responsibilities is also a political choice.
- In political decisions there will be winners and losers.

La Porte began by defining a high-reliability organization as one that must perform nearly perfectly over a period of many management generations of about 10 years each. NASA is such an organization. Most management realizes that the cost of learning from an error is more than the cost of making the error. When managers conclude, in some cases, that the cost of the error is greater than the learning increment, then significant change often occurs. La Porte noted that his research has involved understanding what it means when organizations choose to be better than they need to be, and he expressed that much of NASA has that quality. Researchers have looked at aircraft carriers, nuclear power plants, and air traffic control as organizations that have operated better than they should. Research on high-reliability organizations considers what actually happens when managing large-scale systems that involve highly hazardous operations that require operational stability for many years. What are you actually asking for? What is present in organizations that try to do this?

La Porte explained that researchers do not know how to produce organizations that are highly reliable and that high reliability is often achieved through evolution. There are recognized characteristics of these reliable organizations, however. La Porte noted that in trying to understand highly reliable organizations, researchers look at what happens inside the organization to prevent a particular undesirable outcome and look at the institution's external relationships. Highly reliable organizations tend to have operations that are collegial and highly collaborative, as well as decentralized authority, particularly as the tempo increases in complexity. He said that these organizations have flexible decision-making processes that involve operating teams in which the teams become the central decision makers, and processes that reward the discovery of error, including one's own error. La Porte mentioned that the point is that if you reward the discovery of errors, they are not covered up. La Porte also described that one of the most interesting aspects of high-reliability organizations is what happens in interactions with those outside the organization, even at the risk of some loss of internal control. The processes that organizations use to maintain reliability are costly in time, dollars, and loss of status; in other words, higher-level officials don't like to give up control, especially when it involves decisions for which they can be punished. He explained that highly reliable organizations also tend to be characterized by a strong presence of outside stakeholder groups or "watchers," and such organizations let people on the outside know what is going on right away so they can assist the organization. Highly reliable institutions tend to believe that technical personnel are highly capable, give them room to operate, and protect those personnel when they do their jobs. He stated that an organization needs the whole pattern of characteristics happening at once.

La Porte discussed institutional constancy. When you take the issues of complicated organizations dealing in hazardous operations such as NASA has and you have within the mission a time frame that extends across multiple generations (40 to 50 years or roughly 10 presidential terms), "how," he asked, "do you ensure constancy of commitment? How do you develop characteristics such that people who make bargains with you now will keep them in the future? How do you demonstrate that you have the political will to persist?" Political will from the top is crucial and requires strong commitments from high-status agency leaders and public watch groups. La Porte also pointed out that institutional constancy requires adequate resources to ensure the transfer of technical and institutional knowledge across worker and management generations; an institution cannot rely on internal, ad hoc transfer of knowledge. For example, how long can an institution fail to do the things it needs to do before the next generation cannot learn them, he asked. A significant portion of technical operations are not technical, but an art of operations, he explained. In many cases, engineers and operations personnel cannot explain what they do; they lack a language to describe their actions. Continuous, explicit transfer of knowledge is critical. We need to ask how this process works in NASA, he observed. He also questioned whether we have the capacity to detect and remedy the early onset of the failures that could threaten the future of a program



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and whether we have the means to remediate the failures if they occur. La Porte also asked if we understand the organization enough to detect that if "this" continues to unfold, then we will have a catastrophe in the program.

La Porte discussed what might be done if we are concerned about maintaining public trust. NASA is verging on losing public trust. If you've lost the trust in an organization, what you need to do to recover it is extraordinary, he said. You cannot recover trust in a hurry, he said, and you need to change yourself a great deal. We are not just concerned about a technical program or about priorities among an agency's technical activities. Public trust and confidence are also about how you comport yourself as an institution. He described the situation as one in which the space program needs high reliability over many management periods (presidential terms) in an environment of increasing public distrust. These kinds of issues need to be factored into how we think about going forward. Institutional transformations need to take place. Repeated phenomena such as high-level managers engaging in the same behaviors time after time in the absence of an explanation lead to bad outcomes. He reflected that these managers work hard and are well meaning and that perhaps each of us would do the same. Why is this, and how can we change it? La Porte highlighted several questions that need to be understood in the NASA context. If the manned space program is continued at a substantially lower level of effort, how small can the level be before we can't continue to do it? How few people can an organization have and still do its job? How long could you fail to do things before it's impossible to recover? What do you need to know and capture in case the program collapses? The sadness, he commented, is that we have had immensely interesting human capacity demonstrated in the space program over the last 20 years. We need to know more about what it really took to do that.

La Porte mentioned that he was struck by the tacit agreement that everyone at the workshop appeared to share regarding the cultural aspects of the space program, and he suggested that those beliefs need to be expressed publicly. What is the cultural contribution of the space program in the symbolic sense? What does it mean to our public to have enjoyed what we've had over the last 20 years? What would it mean to have lost this opportunity? La Porte pointed out that no one is telling the story of what it would mean to focus on other questions in the political sphere and abandon a permanent presence in low Earth orbit. He acknowledged that gaining such understanding is extremely important, yet very difficult, and it is not the kind of activity that National Academies' panels do comfortably.

The subsequent discussion focused on the issues of organizational reliability necessary for moving forward with the space program and questions about changes needed within the institutional structure of NASA. Jacobson was struck by the requirements for high reliability and their effect on organizational structure. "What if we accept the current reliability of the shuttle?" he asked. Would this help or hurt the issues outlined? Participants suggested that the national conversation would be different and questioned whether NASA leaders could sustain support in Congress if they talked realistically about what they were doing. Do we have science to die for? Wheelon mentioned that the sin is to call the shuttle something other than a flight test program. There is a mismatch between reality and rhetoric. Frosch noted that if we used all five shuttles with as many flights as they were supposed to fly, then we would have just the approximate number of flights needed to flight certify the Boeing 747 commercial airplane.

Osborn pointed out the parochialism of scientists. She reported that the NASA Research Maximization and Prioritization (ReMaP) task force was charged with defining the science that should be done on the ISS and with assigning priorities among those areas of science. The task group hurt its own credibility because some members could not compromise on priorities. Scientists can't always affect policy positively, but they can greatly affect policy negatively, she concluded.

Fisk asked, "If you're defining space policy, do you have to say that there needs to be a fundamental change in NASA and the space program? If we want to do it differently, do we have to restructure NASA? Is there an example of a federal agency that has transformed itself to some better state, and if so, how was it done?" La Porte commented that there are no examples of organizations that have changed, though there are examples of subunits that have changed, and one is Rocky Flats, a Department of Energy weapons facility.



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# 7
# Boundary Conditions for Forging a 21st-Century Space Policy

The session was moderated by SSB member Steven Flajser, an aerospace industry executive and former staff director of the Senate Science, Technology, and Space Subcommittee. Participants included Dan Fink, consultant and former senior executive at General Electric; Robert Frosch, professor of public policy at Harvard University and former NASA administrator; and Richard Malow, consultant and former clerk of the House VA, HUD, and Independent Agencies Appropriations Subcommittee. Participants were asked to consider the following questions:

- What are key considerations for changing policy or constraining factors toward a renewed national space policy?
- What should be key elements for a strategy for reaching consensus on the purposes of the space program?

Fink began by summarizing his participation on the Augustine Committee[1] in 1990. He noted that the committee had a broad charge and reported to the Vice President of the United States, who served as chair of the National Space Council. Fink observed that many aspects of the context for that study were the same then as they are today. NASA was (and is) confronted with cost increases, program delays, budget pressures, overcommitment, institutional aging, and the aftermath of a tragic shuttle accident. He added that there had also been many NASA successes, especially in science.

Fink then asked, "What are the differences between then and now?" He noted that the world was more peaceful then because the Cold War was essentially over, whereas today terrorism is a dominant threat. Fink indicated that it was much harder to gain a consensus on goals for the space program then than has been the case at this workshop. As to why consensus was more difficult then, Fink concluded that the NASA Advisory Council report on the crisis in space and Earth sciences[2] had just been released and that there was much more animosity between advocates for the robotic and manned space programs then than now. He noted that at the time of the Augustine report supporters of human space exploration were most often culturists rather than scientists. Fink said, for example, that Daniel Boorstin, former Librarian of Congress and author of *The Discoverers,*[3] made the most articulate statement about human exploration and its value to the nation.

The Augustine Committee recommended a 5-point, balanced space program. Science was the highest-priority centerpiece of the program, and they recommended that it continue to be funded at about 20 percent of the NASA budget. The space technology base was viewed as weak, and the committee recommended that it be strengthened. They also recommended a heavy-lift launcher and a crew recovery vehicle. Further, Fink said the committee recommended the Mission to Planet Earth and Mission from Planet Earth[4] programs in NASA. The latter program was characterized by an essential mix of both

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[1] Advisory Committee on the Future of the U.S. Space Program, *Report of the Advisory Committee on the Future of the U.S. Space Program,* U.S. Government Printing Office, Washington, D.C., December 1990. In brief, the report, also known as the Augustine Report, made the following points: Establish space science as the highest priority of the civil space program; convert some NASA centers to the university-affiliated JPL model; redesign the space station to reduce complexity and cost; pursue Mission from Planet Earth and Mission to Planet Earth; and use heavy-lifting ELVs instead of the shuttle whenever possible.

[2] Space and Earth Sciences Advisory Committee of the NASA Advisory Council, *The Crisis in Space and Earth Sciences*, November 1986.

[3] Boorstin, Daniel, *The Discovers: A History of Man's Search to Know His World and Himself*, Random House, New York, 1983.

[4] Mission to Planet Earth was a NASA program focused on space-based observation of Earth as a means for collecting data and conducting research that leads to understanding and prediction of the global change on our planet. Mission from Planet Earth was a NASA program inspired by President Bush's 1989 address on the 20th Anniversary of the Apollo 11 Moon landing in



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human and robotic elements. Reading from the Augustine Report, Fink quoted from the Executive Summary statements about the committee's views on the manned space program:

> But are there not activities in space which properly should be the province of human intelligence, flexibility and being? The Committee found it instructive in this regard to ask whether we would be content with a space program that involved *no* human flight. Our answer is a resounding "no." There *is* a difference between Hillary reaching the top of Everest and merely using a rocket to loft an instrument package to the summit. There *is* a difference between the now largely forgotten Soviet robotic Moon explorer that itself returned lunar samples, and the exploits of astronauts Neil Armstrong, Buzz Aldrin, and Mike Collins. The Committee thus wholeheartedly endorses a far-reaching, but we believe realistic, undertaking in manned space activity, carefully paced to the availability of funds.
>
> But if there is to be a manned space undertaking, what should it be? Surely the goal is not merely to provide routine transportation of cargo to and from space. In this regard, we share the view of the President that the long term magnet for the manned space program is the planet Mars—the human exploration of Mars, to be specific. It needs to be stated straightforwardly that such an undertaking probably must be justified largely on the basis of intangibles—the desire to explore, to learn about one's surroundings, to challenge the unknown and to find what is to be found.[5]

Fink continued to quote from the report,

> The Committee offers what we believe to be a potentially significant new approach in the planning of human space exploration. Although we appreciate the arguments for setting a "date certain" for many or even most of our space goals, as did President Kennedy with respect to going to the Moon, we believe that a program with the ultimate, *long term* objective of human exploration of Mars should be tailored to respond to the availability of funding rather than to adhering to a rigid schedule.[6]

Fink said that the Augustine Committee referred to the recommended approach as "go as you pay" and not "pay as you go." Fink noted that the committee did assume that the NASA budget would have a 10 percent annual growth rate; "that's what senior congressional leaders thought at that time," he remarked. Fink recounted that with respect to the space station, the committee said that the station's only justification was as an enabler for long-duration human spaceflight. Fink concluded that the report, despite receiving broad praise, unfortunately had little programmatic impact on NASA.

After indicating his sense that a broad consensus probably exists for an integrated human-robotic exploration program pointed toward Mars, Fink addressed the enabling factors and constraints for achieving such a goal. First, he noted that we don't have the manned versus unmanned tensions that existed in 1990. In remarking on constraints, he referred to the fact that we can't count on 10 percent annual growth in the NASA budget, but we can scale back, he said. The question is, how far can you scale back and for how long? He noted the need for a broad technology architecture study, including looking at the technology, the robotic missions, the integration of robotic missions, and a determination on whether it is or is not necessary to have a Moon program as a precursor to human exploration of Mars. He questioned whether we have the people and talent in any one organization to conduct such a study. Neither NASA nor industry has the depth that it once had. Fink mentioned the DOD STRAT-X activity in the 1960s, which was a review of our strategic successors to the Minuteman and Polaris. A group was put together consisting of military personnel, government civilians, contractor personnel, and consultants, supported by a federally funded research and development center that ran for a period of about 6 months.

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which he called for the nation to lead a "sustained program of manned exploration of the solar system," an initiative that was later called the Space Exploration Initiative.

[5] Advisory Committee on the Future of the U.S. Space Program, *Report of the Advisory Committee on the Future of the U.S. Space Program,* U.S. Government Printing Office, Washington, D.C., December 1990, p. 6.

[6] Advisory Committee on the Future of the U.S. Space Program, *Report of the Advisory Committee on the Future of the U.S. Space Program,* U.S. Government Printing Office, Washington, D.C., December 1990, p. 6.



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Fink suggested that this is the kind of approach that we may need to consider to undertake a technology architecture study.[7]

In discussing other constraints affecting the U.S. space program, Fink said the issue of how to handle the international roles involves the question of trust. "Is the trust so eroded that whatever is said is not believed?" he asked. Regarding the need to achieve a broad national consensus, Fink commented that first we need a good story, and then we need to get someone who can deliver that story in a way that is inspirational. It's not an easy sell. He also suggested the need for a long-term follow up on the report issued from this workshop.

Frosch opened his remarks by arguing that there is a clear and accepted reason for exploration, either manned or unmanned. People explore; it is what we do. We stroll around the world and see what it is really like instead of imagining what it is like. We experiment with theoretical and mathematical concepts to explain the universe, and then we look to see what is logically consistent, he said. Frosch said that in this sense exploration is a part of science.

Frosch said that he would describe a path to Mars but that it could apply equally well to the goal of going to the Moon. First, there have to be robots, teleoperators, and people working in tandem, with the robots and teleoperators recognized as tools of the people. Frosch noted that Norbert Wiener referred to this as the human use of human beings.[8] Second, we don't know how long people can live and work in space. To answer that we will need ground and space experiments. Third, he said, we will need technology for shielding against radiation, and we will have to do a lot more to develop robotics and teleoperators, adding that "we've barely done enough." Frosch asserted that we haven't built the right interface for our teleoperators, and he stressed that we should begin with teleoperations from Mars orbit and guided autonomy on the ground, after which we can move to the surface of Mars where humans can undertake tasks that robots cannot perform. This approach embraces a "buy it by the yard" strategy.

Frosch proposed the following points as critical steps to reforming the space program:

- *Reconstruct NASA with a new leadership style.* Reconstructing NASA might even require dismantling the agency in order to rebuild it. Reconstruction could entail changing the way NASA field centers are managed. We need to reclaim vertical communication that is more open. Both shuttle accidents (*Challenger* and *Columbia*) started in way that suggests that the agency will need outside help in creating more open communication. Frosch said, "Accidents begin in the Administrator's office," explaining that, while the leadership is not the proximate cause of the accident, the management and communication style of the organization and its leaders is important to safety. NASA needs outside input from the social sciences (e.g., on the psychology of organizations) in exploring critical leadership and management issues. While addressing these issues we need to take care not to damage the good aspects of today's NASA.
- *Build coalitions.* Convene international partners, offer them our version of the solutions and vision, and solicit their version of what they think we should do. Then put together a human exploration endeavor in which we are prepared to pay for the major fraction. We also need to convene our internal political powers and try to get some kind of political agreement on which way to go with the space program. The public must be engaged, as well.
- *Establish the right kind of collaboration.* There is a version of collaboration that is different from providing something for everyone. There can be an agreed plan to do something, which people do for different motivations. There's nothing wrong with mixed motivations as long as all agree to do something specific together.
- *Keep NASA technologically strong.* If NASA is not internally competent, then it cannot even be a smart buyer and know if people outside are doing the right thing.

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[7] Institute for Defense Analyses Research and Engineering Support Division, *The Strat-X (U) Report*, Vol. I, August 1967, declassified in 1978.

[8] Wiener, Norbert, *The Human Use of Human Beings: Cybernetics and Society,* Doubleday, Garden City, New York, 1954.



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- *Build on what we have.* Consider what we already have and determine if there are ways to turn it to our purpose for what we want to create. We can probably use the shuttle and a lot of the ISS if they are used in a different way. We may even have to take some of the ISS apart and use the pieces in a different way.
- *Press the technological envelope.* The concept of self-replicating machines deserves serious attention. There are three technological possibilities to consider—conventional factories, nanotechnology, and biotechnology.

Malow opened his remarks by noting major differences between science and human spaceflight when he was working with Congress and also today. Space science has set clear goals and has stuck to them, and that is very successful. He suggested that what is missing from human exploration is that exploration has been in the capability-building stage but has not had clear goals.

Malow said he was struck by the monetary figures described by Wheelon for science and for human exploration. He noted that the science funding level has come much closer to the human spaceflight number than it has ever been. In the 1980s, everyone said that the science program would never survive if it wasn't for the human side. Now, they might say that science has basically saved NASA. He added that if the Mars rovers are successful in early 2004, public interest in the space program will increase. That magic is missing from the human side of the equation, he remarked. We aren't going to give up on human spaceflight, but we have dug a deep hole for ourselves and it's deeper than he has ever seen it.

Malow cited two examples of problems. First, we have a space transportation system and an ISS that are not effectively delivering what they were intended to deliver. Second, during the 1990s, as we came into a federal surplus, the NASA budget declined in real dollars by almost $2 billion, and there is a tendency to get locked in to a budget envelope. Malow argued that we lost the opportunity to get the NASA budget up another 10 to 20 percent and are now facing a headwind (with growing deficits) that is not going to go away.

Regarding the problems with the space station and the shuttle, Malow reflected that we're at a crossroad with the *Columbia* accident. He suggested that we have to decide whether to fix what we have, noting that if we get to ISS core complete we will have only marginal capability on the ISS. To take the path of truly fixing the ISS, he commented, would cost billions of dollars. Another possibility is that we go to our international partners and tell that the space station effort didn't turn out the way we thought it would, set a date for getting out of the ISS, and move on to something that is a grand alliance. Malow said he was worried that the nation will decide to do neither, and that we will build an orbital space plane that would only deepen the hole.

Malow noted that he leans toward the idea of getting out of what he called "the low Earth orbit black hole." If we're going to pick a grand goal, it should probably be Mars, he suggested. While going back to the Moon is an alternative, it has a sense of "been there, done that" to it. Mars presents the chance to excite the public. Malow stated that we need a political consensus that a human mission to Mars can be done and that we will stick to it. We have a different political climate than existed in 1961, 1969, or 1972. Then there was controversy about the shuttle, but there was a consensus that we were going to pursue it. Building political consensus is much tougher today because of the federal deficit, and because Congress is different today. Civility is rarer now. The members are not as interested in the broader spectrum of issues; they are distracted by raising money and getting elected. But, Malow stressed, we still should try to get congressional consensus on a grand goal. If we could pick a long-term goal that would capture the public's interest and have the consensus support of policy makers, we might be able to pull it off. But if we play around in low Earth orbit and just continue to enable that capability, we're never going to reinvigorate human spaceflight with an exciting goal.



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# 8
# Coming to Closure

Lennard Fisk opened the final session for general discussion and invited all participants to offer comments on the principal messages and themes that they saw emerging from the workshop.

Edward Stone said that NASA's role was clear when it was founded. The agency had to help make the United States a space-faring nation. Now the United States is a space-faring nation, and if there was no NASA now, it would still be a space-faring nation. So the question has to be asked, Why NASA? Stone said that in his opinion, space is still the newest realm of human activity. NASA's job is to continue to expand the frontiers in this realm, with its international partners when appropriate. Stone said there are five frontiers in space, namely:

1. The physical frontier,
2. The knowledge frontier,
3. The technology frontier,
4. The human frontier, and
5. The applications frontier.

In Stone's opinion, it is NASA's role to invest in these frontiers, to learn about them, and to expand them. Such learning entails risk, but if we demonstrate that we are learning new things then we have a way to measure risks, benefits, and costs. Stone said this is technical risk, not institutional risk. Each program at NASA has to expand one or more of these frontiers. Because these frontiers are immense, choices must be made. Among the criteria for such choices is the extent to which expanding a frontier contributes to the achievement of a longer-term goal. Human spaceflight should expand the physical frontier, eventually extending that frontier to Mars. The United States is not ready to go to Mars yet, though—the space program first has to expand the human frontier by learning about the psychology and physiology of long-term spaceflight. That should be the role of the ISS.

In expanding these frontiers, Stone said that the United States should pay special attention to its rate of learning. The rate of learning suggests an exit criterion—when you stop learning you move on to the next step. The rate of learning in human spaceflight has to be greater than in other areas, given its level of investment and high risk.

To learn most effectively, Stone said that the United States should move away from the occasional, large systems with very long development times and move toward systems that tackle these frontiers on shorter time scales. NASA should establish 5-year programs, or similar concepts, which focus on the engineering of new systems, a high rate of learning, and then preparation for moving on to the next step. The success of the space sciences at NASA has demonstrated that when NASA can make good progress and demonstrate real success, the progress will be rewarded. NASA can demonstrate real progress toward the goal of Mars, or toward any goal for that matter, without having to make a commitment to a date or to a specific location. But if that goal does not become inevitable, it will never be reached, and it will never become inevitable if the United States does not push these frontiers.

Fink followed up on Stone's remarks by saying that the nation needs an architecture and that perhaps the frontiers idea can serve as the basis for that architecture. The frontiers can help identify what steps are needed to get to Mars or any other destination. However, Fink pointed out that there has to be a full-time effort to plan how to progress along these frontiers. Only a full-time effort can produce the interim steps that are technically feasible and that can fit into the political environment. Hinners agreed and indicated that he thought NASA's science programs have had success because they actively involve the science community. There is a peer review process, and there is some measure of tension between the space agency and the scientific community. This tension and interaction ultimately improve science. The human spaceflight part of NASA is missing this constructive tension, as he called it, and Hinners



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wondered about who could add it. Who could be involved on a permanent basis? Fisk agreed and said he believed that the architecture for long-term goals or plans should not necessarily be left to NASA alone. Giacconi indicated that he also agreed with Stone and said that it is important to have a precise goal, because without it small steps and good learning can continue on in a way that is similar to the space program's current lack of direction.

Giacconi then commented on what he saw as a defeatist attitude, which was something he found very strange. He asked how it could be that the United States could have a space agency with a $15 billion budget and not have the boldness to articulate goals for that agency. The U.S. space program must have a goal. NASA and the space community should not go to Congress and ask, "Do you want us to do something like this?" Rather, NASA should approach Congress and say, "We want to do this." Then let Congress make its decision. He wanted the people in the room to be enthusiastic, saying that ultimately the space program can't please everyone, but it must take a stand.

Craig Wheeler agreed with the need to establish a clear goal as well. Wheeler also agreed that it would be wrong to specify a time line for the goal, but argued that we should begin by setting out along the frontiers defined by Stone. Wheeler indicated that Mars is sometimes mentioned with reticence because of its high cost, and it has to be taken out of the closet. There are ways to define excellent science questions about Mars to specifically define Stone's frontiers. A particular issue to pursue with new and renewed vigor is the question of whether Mars has in the past harbored life or does now harbor life. A single example of Martian life, like it or not, would fire the public's imagination. The quest for life on Mars could help identify how best to integrate both robots and humans. In Wheeler's mind, this kind of approach would require more openness from NASA than it has offered in the past. It would require candor about how to salvage the ISS. Wheeler believed that NASA cannot afford to be viewed as less than fully open and honest in establishing its next goal.

Several participants followed up on Wheeler's remarks about the need for a clear long-term goal, and about how to achieve that goal. They saw a connection between the issue of whether NASA is viewed as being entirely honest and Giacconi's remarks regarding a defeatist attitude. They indicated that there is a trust issue related to NASA. These participants felt that perhaps this lack of trust contributed to the attitude described by Giacconi.

SSB member Michael Freilich discussed what he saw as points that were reinforced by the discussion. The first was a distinct lack of institutionalization of a process for the infusion of new people and new ideas in the human spaceflight program. This does not refer to the astronaut corps, but to the upper level. Some risk comes with new people and new ideas—they might make mistakes. However, they might not make the same mistakes over again. They might not "normalize deviance," a process described by Diane Vaughan in her book[1] about the *Challenger* accident and referred to again as part of the *Columbia* accident investigation. New people and new ideas might make the program safer in the end. There is no institutional plan to bring in new ideas at the top for human spaceflight. The Rogers Commission report on the *Challenger* accident, the CAIB report, the Augustine Report—none of them found that NASA has such a plan. Freilich agreed with Hinners that the process of peer review and the kind of interaction that NASA's science program has with the scientific community both improve the program, because they are a way of bringing in those new ideas at the top.

Freilich's second point was that NASA in general has not done a good enough job in technology development. Referring to the Space Act, Freilich said NASA is supposed to be a technology development agency, among its other responsibilities, but it does not send out missions that use the newest possible technology. Somehow NASA has lost sight of how best to develop the newest technology, and this affects the willingness of the next generation of scientists and engineers to work in the space program. Frosch agreed, commenting on the value of external people to add new ideas for program and technology development, as well as for careful reexamination of the processes within the agency.

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[1] Vaughan, Diane, *The Challenger Launch Decision: Risky Technology, Culture, & Deviance at NASA,* University of Chicago Press, 1996.



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Ingber elaborated on Freilich's comments about technology development. Advanced technology development is what is important, not just to the space aspects of national security and commercial successes, but to the broader national security and commercial needs of the United States as well. NASA in the beginning did develop advanced technologies, but now it is a shuttle maintenance program and a station maintenance program, so advanced technology development doesn't seem to happen anymore. But the potential for space technology to drive new technology is overwhelming, and that's what NASA should be doing. Ingber believed that this could be a way of helping to prove the value of the program to the nation, similar to the way that the National Institutes of Health can justify its programs to the nation—the money put in brings back so much value. If technology can drive short-term goals along the lines of the frontiers, that could help generate the next technology wave that will push the country forward. Space exploration can generate systems engineering projects that mix robotics, biology, physics, chemistry, engineering, and complex systems. These projects can bring a new level of excitement and new young people into the program.

SSB member Roger Blandford offered his own summation by saying that he could not recall a meeting where he disagreed so little with what was being said or heard so much agreement on some of the general principles—the need for a clear, well-enunciated goal, the need for a clear set of steps toward that goal based on learning, the need for better technology development, and the embracing of the general principles of Stone's frontier model. He sensed that there was a real willingness in the room to continue human exploration. He felt that this was an important point—that there were hard-core scientists in the room who agreed on the need to do exploration and the value of exploration, scientists who had previously been antagonistic toward the manned space program. He also was happy to hear an agreement to stop the debate over humans versus robots and to start thinking about how to integrate humans and robotics in order to explore the solar system in the most optimal manner. Furthermore, he felt that he heard shared views that it is premature to set an absolute date for a destination—that there is still much to learn, but there is value in proceeding in stages and learning along the way. He said that to enunciate a specific goal is not necessarily the job of the Space Studies Board or the workshop. The specific goal will be decided through the political process. But, he said, the Board and the workshop can inform that process.

Fisk brought the workshop to a close by congratulating the participants on an open, frank, and articulate discussion. He offered seven general conclusions that he drew from the workshop discussions, as follows:

1. There are five space activities in the United States: national reconnaissance; military space; commercial space; unmanned space and Earth science; and human spaceflight. The first four have clearly defined goals and motivations. Human spaceflight needs better defined and articulated goals.
2. The primary motivation for the human spaceflight program should be to explore. There is a visceral sense, a perhaps undocumented but strongly held belief, that there is an innate human need to explore, which the human spaceflight program can satisfy.
3. There is no longer a need for the human space program to be a demonstration of U.S. technological prowess; there are many other such demonstrations. But there is a role for human spaceflight to be a demonstration of U.S. leadership and goodwill. This is particularly important at a time when many in the world view the United States with suspicion. However, to be a leader there must be others who are active participants. We should not pursue a human spaceflight program *on behalf* of humankind—that is another form of arrogance—but *together with* the other nations.
4. Exploration is a legitimate form of science, if properly conducted. There is a need to incorporate defendable, legitimate science into the human exploration endeavor. It has to be done with robotics and humans in concert.
5. Implicit in the goal to explore is the necessity to leave low Earth orbit. The goal of extending human presence beyond Earth orbit should thus define the exit strategies for the shuttle and the space station, each of which as currently defined is a dead end.



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6. Extending human presence beyond Earth orbit is a long-term goal that will be difficult to sustain. There must be visible short-term milestones that are achieved with demonstrable success. It is possible to pursue a level-of-effort program to achieve these goals, one that retains public support, similar, for example, to the support for the long-term goal of the National Institutes of Health to cure disease.

7. Related to the notion of a loss of confidence in NASA, the nation and the Congress will have to ask some very difficult questions about the space program and its political support. We need to recognize the current inadequacy of NASA to execute these goals for human spaceflight, and thus the most radical change may need to be to change the structure and mission of NASA. NASA's role in developing new technology needs to be emphasized, and trust must be earned and returned to reinforce NASA's capabilities to execute the nation's desire to go forth into space.

Fisk concluded his summary by saying that he was struck by the possibility that the time may have come when the science community, in the broadest sense, might embrace the idea that there is in fact a role for the human spaceflight program and then steer it in the direction of efforts that will produce valid science—using science in the broadest sense of the word—for exploration. If the community can say "we want to do this", if the community can say "we as a group of scientists, we as the leaders of the scientific community, believe this country should invest in that activity" and then be prepared to stand up and say how to do it, to make a case to the world that this is a valid use of the nation's resources, then that will be a significant milestone.



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# Appendixes

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# Appendix A
# Workshop Agenda

**Workshop on National Space Policy**

**Space Studies Board**
**Aeronautics and Space Engineering Board**

Arnold and Mabel Beckman Center of the National Academies
Huntington Room
100 Academy Drive
Irvine, California
November 12-13, 2003

**WEDNESDAY, NOVEMBER 12, 2003**

| | | |
|---|---|---|
| 9:00 AM | Welcome and Introduction | W. Hoover, L. Fisk |
| 9:15 | **Origins of U.S. Space Policy**<br>History, lessons learned, and implications for today | |
| *Remarks:* | *J. Logsdon* (moderator), *H. McCurdy* | |
| 10:15 | Break | |
| 10:30 | **Rationale for the Space Program, Part 1**<br>What are the contributions of science and exploration to broader national interests?<br>Is the new knowledge created by science the ultimate objective of the U.S. space program, or is it a by-product of space activities carried out for other reasons?<br>What are the contributions of humans in space as researchers, as explorers, as motivators? | |
| *Remarks:* | *M. Urry* (moderator), *R. Giacconi*, *T. Jones*, *W. Huntress*, *D. Newman*, *M.J. Osborn* | |
| 12:30 PM | Lunch | |
| 1:30 | **Rationale for the Space Program, Part 2**<br>How should one weigh the interactions between national security, military, and civilian space efforts?<br>Will space become an economic center of gravity?<br>What are the contributions of space activities to U.S. foreign policy objectives? | |
| *Remarks:* | *R. Jacobson* (moderator), *D. Cromer*, *N. Neureiter*, *J.R. Thompson* | |
| 3:00 | Break | |



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| | |
|---|---|
| 3:15 | **Guiding Principles of a 21st-Century Space Policy**<br>What principles should apply for setting goals and priorities and defining balance?<br>What are the implications for defining institutional roles and responsibilities and other organizational factors? |
| *Remarks:* | *G. Paulikas* (moderator), *N. Hinners*, *T. La Porte, R. Richardson, A. Wheelon* |
| 5:30 | Reception and dinner, Beckman Center |

**THURSDAY, NOVEMBER 13, 2003**

| | | |
|---|---|---|
| 9:00 AM | Opening remarks | L. Fisk |
| 9:15 | **Boundary Conditions for Forging a 21st-Century Space Policy**<br>What are key considerations for changing or setting national space policy?<br>What are the key enabling or constraining factors toward a renewed national space policy?<br>What should be key elements for a strategy for reaching consensus on the purposes of the space program? | |
| *Remarks:* | *S. Flajser* (moderator), *D. Fink, R. Frosch*, *R. Malow* | |
| 10:15 | Break | |
| 10:30 | **Summary and Wrap-Up** | |
| *Remarks:* | *L. Fisk* (moderator)<br>*Ad hoc panel drawn from selected workshop participants* | |
| 12:00 | Adjourn<br>Lunch buffet, Beckman Center | |



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# Appendix B
# Workshop Participants

## PANELISTS

Dan Fink, Consultant
Robert Frosch, Harvard University
Riccardo Giacconi, Johns Hopkins University and University Research Associates
Noel Hinners, Lockheed-Martin (retired)
Wesley Huntress, Carnegie Institution of Washington
Thomas D. Jones, Consultant
Todd R. La Porte, University of California, Berkeley
John Logsdon, George Washington University
Richard Malow, AURA
Howard McCurdy, American University
Norman Neureiter, Texas Instruments (retired), Department of State through September 2003
Mary Jane Osborn, University of Connecticut Medical School
Robert Richardson, Cornell University
Edward C. Stone, California Institute of Technology, U.S. Representative to COSPAR
J.R. Thompson, Orbital Sciences Corporation
Albert Wheelon, Hughes Aircraft Company (retired)

## SSB MEMBERS

Lennard A. Fisk, University of Michigan, *Chair*
George A. Paulikas, The Aerospace Corporation (retired), *Vice Chair*
J. Roger P. Angel, University of Arizona
Ana P. Barros, Harvard University
Reta F. Beebe, New Mexico State University
Roger D. Blandford, Stanford University
James L. Burch, Southwest Research Institute
Radford Byerly, Jr., University of Colorado
Howard M. Einspahr, Bristol-Myers Squibb Pharmaceutical Research Institute (retired)
Steven H. Flajser, Loral Space and Communications, Ltd.
Michael H. Freilich, Oregon State University
Donald Ingber, Harvard Medical School
Ralph H. Jacobson, Charles Draper Laboratory (retired)
Tamara E. Jernigan, Lawrence Livermore National Laboratory
Margaret G. Kivelson, University of California, Los Angeles
Bruce D. Marcus, TRW, Inc. (retired)
Harry Y. McSween, Jr., University of Tennessee
Dennis W. Readey, Colorado School of Mines
Anna-Louise Reysenbach, Portland State University
Carolus J. Schrijver, Lockheed Martin Solar and Astrophysics Laboratory
Robert J. Serafin, National Center for Atmospheric Research
Mitchell Sogin, Marine Biological Laboratory
C. Megan Urry, Yale University
J. Craig Wheeler, University of Texas, Austin



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## ASEB MEMBERS

William W. Hoover, United States Air Force (retired), *Chair*
Donald L. Cromer, United States Air Force (retired) and Hughes Aircraft Company (retired)
Dava J. Newman, Massachusetts Institute of Technology

## INVITED GUESTS

Bill Adkins, House Committee on Science
Marc S. Allen, NASA Headquarters, Office of Space Science
Andrew Christensen, The Aerospace Corporation, chair, Space Science Advisory Committee
John Cullen, Senate Commerce Committee
Gerhard Haerendel, International University, Bremen, ESSC Chair
John Mimikakis, House Committee on Science
Richard Obermann, House Committee on Science
Jean-Claude Worms, European Space Science Committee



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# Appendix C
# Statement of Task

**Workshop on National Space Policy**
**November 12-13, 2003**
**Arnold and Mabel Beckman Center**
**Irvine, California**

Space Studies Board
and
Aeronautics and Space Engineering Board

The workshop will utilize brief presentations, panel discussions, and general discussions to explore aspects of the question "*What should be the principal purposes, goals, and priorities of U.S. civil space*?"

To do so, the workshop participants will be asked to consider the following questions:

1. What mixture of cultural, social, economic, and geopolitical factors has led the United States government to invest substantially more in the civilian space program than any other nation, both in absolute terms and as a portion of national wealth?
2. What is the appropriate balance among these factors as the nation carries out a searching reassessment of its space policies and programs in the aftermath of the Columbia accident?
3. What are the appropriate roles of the federal government?
4. Is the level of investment today appropriate, too high, or too low, given other demands on the Federal budget?
5. What principles should be applied in setting priorities for space activities?
6. What principles apply to defining proper balance across space activities?
7. What role does in-situ human presence play in achieving the purposes that drive government investment in space?
8. What principles should guide risk-benefit assessments for human space flight?
9. What should be the balance between humans and robots?
10. What should be the role of the International Space Station?
11. What are our needs for space transportation systems?

The goal of the workshop will not be to develop definitive answers to these questions but to air a range of views and perspectives that will serve to inform later broader public discussion of such questions.

A summary report of the workshop, which will include extended abstracts of remarks prepared by individual panelists, will be published by the National Research Council soon after the workshop.



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# Appendix D
# Biographies of Workshop Speakers

**Donald L. Cromer** recently retired as president of the Hughes Space and Communications Company (HSC). Prior to joining HSC he had a 32-year career in the U.S. Air Force, culminating in promotion to Lt. General and command of the Space Division. He is a member of the National Research Council's (NRC's) Aeronautics and Space Engineering Board.

**Daniel J. Fink** is president of D.J. Fink Associates, Inc. He has served as deputy director of defense research and engineering at the U.S. Department of Defense (DOD) and in a number of executive positions at General Electric, including senior vice president of corporate planning and development. He is a member of the National Academy of Engineering and was a member of the Advisory Committee on the Future of the U.S. Space Program and of the NRC Space Studies Board.

**Lennard A. Fisk**, workshop co-chair and chair of the NRC Space Studies Board, is the Thomas H. Donahue Professor of Atmospheric, Oceanic, and Space Sciences at the University of Michigan. From 1987 to 1993, Fisk was the associate administrator for space science and applications and chief scientist of NASA. He is a member of the National Academy of Sciences.

**Robert A. Frosch** is senior research fellow at the Center for Science and International Affairs at Harvard University's John F. Kennedy School of Government and a senior fellow at the National Academy of Engineering. He was administrator of NASA under President Carter and later became vice president for GM Research Laboratories, later the General Motors Research and Development Center.

**Riccardo Giacconi,** a co-recipient of the 2003 Nobel Prize in physics, is a research professor in the Physics and Astronomy Department of the Krieger School of Arts and Sciences at the Johns Hopkins University and president of Associated Universities, Incorporated. He was the first director of the Space Telescope Science Institute. Giacconi is a member of the National Academy of Sciences and has served as a member of the Space Studies Board.

**Noel W. Hinners** is a former vice president of Lockheed Martin Astronautics with responsibility for NASA planetary flight systems. He has been associate deputy administrator and chief scientist of NASA, director of the NASA Goddard Space Flight Center, associate administrator of the NASA Office of Space Science, and director of the Smithsonian's National Air and Space Museum. Hinners is a former member of the Space Studies Board and chair of its Committee on Human Exploration.

**William W. Hoover**, workshop co-chair and chair of the NRC's Aeronautics and Space Engineering Board, is currently a consultant for aviation, defense, and energy matters. He is a former executive vice president of the Air Transport Association of America, former assistant secretary for defense programs in the Department of Energy, and a former Major General, USAF.

**Wesley T. Huntress, Jr.,** is director of the Carnegie Institution's Geophysical Laboratory. From 1993 until his 1998 departure for Carnegie, he was associate administrator for space science at NASA Headquarters.

**Thomas D. Jones**, a former NASA astronaut and veteran of four spaceflights, is an aerospace consultant, writer, and speaker. After piloting strategic bombers for the Air Force, he earned a doctorate in planetary sciences. He worked as a program management engineer at the CIA's Office of Development and



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Engineering, and as a senior scientist at Science Applications International Corporation, supporting the Solar System Exploration Division at NASA Headquarters. His last mission delivered the U.S. science laboratory Destiny to the International Space Station.

**Todd R. La Porte** is a professor of political science at the University of California, Berkeley. His current research focuses on high-reliability organizations and the relationship of large-scale technical systems to political legitimacy. He is a member of the National Academy of Public Administration, and he has served on the NRC Board on Radioactive Waste Management and the Transportation Research Board.

**John M. Logsdon** is director of the Space Policy Institute at George Washington University's Elliott School of International Affairs. Logsdon served on the Columbia Accident Investigation Board and is currently a member of the Commercial Space Transportation Advisory Committee of the Department of Transportation. He has served on the NASA Advisory Council, the NRC Aeronautics and Space Engineering Board, and the NRC Committees on Human Exploration and on Space Policy.

**Richard N. Malow**, consultant to the Association of Universities for Research in Astronomy (AURA), previously served as clerk of the VA, HUD, and Independent Agencies Subcommittee of the House Appropriations Committee. During his 21 years on Capitol Hill, Malow had responsibility for more than 70 appropriations accounts for 20 federal agencies, including the National Science Foundation and NASA.

**Howard E. McCurdy** is chair of the Department of Public Administration at American University. He has authored *Space and the American Imagination*. An earlier book, *Inside NASA: High Technology and Organizational Change in the U.S. Space Program*, was awarded the Society for History in the Federal Government's 1994 Henry Adams prize for the best book on the history of the federal government. His most recent book is *Faster, Better, Cheaper: Low-Cost Innovation in the U.S. Space Program.*

**Norman P. Neureiter** completed a 3-year appointment in September 2003 as science and technology adviser to the secretary of state. An organic chemist from Northwestern University, he has been a researcher in the oil and petrochemical industry, spent 2 years with NSF, served as the first U.S. science attache in Eastern Europe, and was international affairs assistant in the White House Office of Science and Technology during the Nixon Administration. Joining Texas Instruments (TI) in 1973 and working in corporate relations and international business development, he became vice president of TI Asia, residing in Tokyo. After retiring in 1996, he was a consultant to business and government until joining the State Department in 2000.

**Dava Newman** is an associate professor of aeronautics and astronautics at MIT, director of the Technology and Policy Program, and a MacVicar Faculty Fellow. She currently serves on the NRC Aeronautics and Space Engineering Board.

**Mary Jane Osborn** is a professor of molecular, microbial, and structural biology at the University of Connecticut Health Center. Osborn has served on the National Science Board, the President's Committee on the National Medal of Sciences, the Advisory Council of the National Institutes of Health's Division of Research Grants, and the NASA ISS Research Maximization and Prioritization Task Force. Osborn also served as a member of the Space Studies Board and as chair of its Committee on Space Biology and Medicine and is a member of the National Academy of Sciences.

**Robert C. Richardson**, a co-recipient of the 1966 Nobel Prize in physics, is the Floyd Newman Professor of Physics and the vice provost for research at Cornell University. He is a member of the National Academy of Sciences, and he has served on the National Science Board, the NRC Board on



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Physics and Astronomy, and the NASA International Space Station Management and Cost Evaluation Task Force.

**James R. Thompson** is vice chairman, president, and chief operating officer of Orbital Sciences Corporation. He has served as NASA's deputy administrator, director of the NASA Marshall Space Flight Center, and deputy director for technical operations at Princeton University's Plasma Physics Laboratory. He is a fellow of the American Institute of Aeronautics and Astronautics and of the American Astronautical Society.

**Albert C. Wheelon** is the retired CEO and chairman of the board of Hughes Aircraft Company. He served as the deputy director of science and technology for the CIA, where he was responsible for technical collection and analysis activities, including U2 overflights, development of the SR-71, and the development of second- and third-generation reconnaissance satellites. He is an elected member of the National Academy of Engineering.

## Workshop Rapporteur

**Radford Byerly, Jr.,** is a senior fellow at the Center for Science and Technology Policy Research, University of Colorado. He formerly served as chief of staff of the U.S. House of Representatives Committee on Science and Technology. He is a current member of the Space Studies Board, and he has been the editor of two books on space policy.



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# Appendix E
# Abstracts Prepared by Workshop Panelists

## IS A STRONG SPACE PROGRAM STILL IMPORTANT TO THE UNITED STATES?
**Donald L. Cromer**

In the public view, the space program often equals NASA. Outside of NASA, there is a national need for a strong space program. In the broadest sense, the space program serves to meet national security needs by providing the military and national security communities with the ultimate high ground; fosters both a strong and positive image internationally; serves as an important avenue of economic opportunity; and provides inspiration to the future scientists and engineers who are vital to our national technical industrial base.

The benefits to our nation from the space program often arise from the co-development of technologies equally important to the commercial, national security, and civil space communities. In addition, there are often synergies in the application of satellite technologies and services—like the Global Positioning System (GPS), remote sensing, weather, and communications. Communications satellites provide an excellent example of co-development and operational synergy. In the development of Comsat federal efforts have outpaced private efforts, and vice versa, in a kind of cyclical manner over the past 30 years. Currently, the military is dependent on commercial communications satellites for successful operations during combat. The military should, however, utilize commercial assets during peacetime and use dedicated military assets to handle the surge in demand during combat.

Will space become an economic center of gravity? In the broader sense it already is. Space spin-offs are numerous and embedded into many products and services (e.g., commercial GPS for timing, location, and positioning; weather forecasting and reporting; direct-to-home television; and cable distribution). As an industry, the commercial space industry is still emerging. Satellite services already account for billions of dollars in sales with the demand for services expected to grow, particularly in North America and Europe. In contrast, satellite and launch vehicle manufacturing operations are struggling to make a profit. These activities could be a major benefit to broader U.S. interests in trade and commerce, but current restrictive policies on export control are stifling the U.S. space industrial base. In this regard, Congress's decision to place communications satellites on the Munitions List was ill-advised. While previously there had been only anecdotal evidence that this decision had a negative impact on U.S. satellite manufacturers, the recent public comments by Arabsat on its decision to choose EADS over Lockheed Martin has served to reinvigorate this debate. In a broader context, with respect to our foreign policy, space activities can become a leverage tool.

## RECALLING THE AUGUSTINE REPORT
**Daniel J. Fink**

In 1990 the Advisory Committee on the Future of the U.S. Space Program produced its report on new directions and priorities for the space program.[1] Known as the Augustine Report (for the committee chair, Norman Augustine), it is still an invaluable resource for guidance in national space policy. The Augustine Committee had a very broad charter: to advise the nation on "the future of the civil space program," including management issues and program content. The committee did its work over the course of a very intense 120-day period, conducting more than 300 interviews, delivering its final report to Vice President Quayle, who was, at the time, chair of the National Space Council. Included among the

[1] Report of the Advisory Committee on the Future of the U.S. Space Program, U.S. Government Printing Office, Washington, D.C., December 1990.



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membership were four Space Studies Board members: Laurel Wilkening, Joe Allen, Jim Baker, and Lou Lanzerotti.

There are several similarities between the time that the Augustine Committee conducted its work and the circumstances surrounding this current workshop. There is the tragic loss of a space shuttle and its crew, severe criticism of NASA, management turbulence at NASA, institutional aging, and great successes, particularly in the space sciences. There are differences as well. In 1990 it was a time of relative peace, "except for an occasional renegade leader." Now there is a war on terrorism and a plethora of renegade leaders. This changes national priorities compared to 1990. Now there may be a greater consensus on the need for a long-term goal of manned exploration of Mars. Then there was a real animosity between the science community and manned space, with both sides playing a zero-sum game. There was no realization that space science funding would not hold up if the human exploration program disappeared. This is no longer the case.

The Augustine Report had several recommendations, the focus of which was a five-part "balanced" space program, illustrated by a sketch of a scale. Science is the fulcrum of this scale, and it is given the highest priority. In fact, giving science a priority for the whole program is the only time priority is mentioned in that context in the entire report. The supporting arms of the scale were two infrastructure items: space technology and space transportation. The report recommended an unmanned heavy-lift launcher and the two-way transportation of humans. The space station was viewed only as an enabler for long-duration manned flight and other science only if it was easily accommodated. The report then identified two mission areas: Mission to Planet Earth and Mission from Planet Earth. Unfortunately, NASA's overall response to the report was negligible.

What might enable a more proactive response by NASA to the conclusions of this new workshop? Perhaps the growing consensus about and articulation of the need for a specific, mid-to-long-term destination for human spaceflight and exploration will serve as motivation for NASA. Perhaps the recent success of the Chinese in space will serve as motivation as well. One constraint will certainly be financial resources.

The nation needs a thorough technology architecture or roadmap study, defining all the technology steps, robotic missions, and principles for integrating robotic and human programs as we move toward the next destination. An important question this workshop can address is, Does the nation have the people and talent necessary to achieve its desired goals? Perhaps a model for such a roadmap study is the Department of Defense study called "Strat-X." Conducted over the course of several months in the 1960s, the study involved people from government, academia, and industry and was supported by a strong federally funded research and development center. How can we reach a national consensus? Who might be the spokesperson for that consensus? Whatever the answer, the space program will require a very good story delivered in a manner than inspires the nation.

Finally, perhaps the major failure of past efforts is the lack of any follow-up on the part of those who previously sought to advise the nation. For example, when they completed their work, the Augustine Committee disbanded. In producing a report of this workshop, the Space Studies Board must do a better job in following up its observations.

## THE NATURE OF EXPLORATION AND THE FUTURE OF THE SPACE PROGRAM
**Robert A. Frosch**

When considering questions about space policy, one should refer to the National Aeronautics and Space Act of 1958, PL 85-568, as amended. In particular, one should pay special attention to Title I, Sec. 102 (d) and Sec. 103, which set forth basic purposes of the act. The act can fairly be interpreted to mean that the responsibility of NASA for space (the act gives NASA other responsibilities) is to develop knowledge of the universe beyond Earth (space), to develop the technological means to get this knowledge, and to explore. It also implies using this knowledge to learn about Earth. Thus the purpose is



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space science and exploration (the rest of the universe), the technology to do this, and, importantly, applications to Earth.

There is a clear and accepted implication for exploration, manned or unmanned, as appropriate. People explore. It is what we do. We do it in numerous ways:

1. We stroll around the world and see what it is really like, as opposed to what we might imagine it to be like. We would like to stroll around the universe and do the same, but, so far, we are limited to extending our senses and using teleoperators and robots.
2. We experiment: We create parts of imaginable universes to see which one we live in.
3. We examine imaginary theoretical and mathematical possibilities to see which are logically consistent with various assumptions, and we compare these with the results of (1) and (2) above to see which possibilities appear to describe these results. We draw conclusions about what universe we live in. This is called science; it is a form of systematic exploration.

While our capability for robotic and teleoperated scientific observation and exploration has gone very far, it is still far from being equivalent to human observation and experiment on site. Further, the velocity of light and the consequent time delays mean that at great distances teleoperation will continue to be an inadequate means for exploration and experiment. (While robotic and teleoperated means have become routine in oceanography, the oceanographic community continues to value, use, and upgrade manned vehicles.)

This being so, we need a new partnership arrangement in space between people and their machines (Norbert Weiner called it the human use of human beings). Robots and teleoperators should be extensively developed to do large amounts of the work, and people should do what only people can do best, namely observe and deal with the unexpected and the serendipitous: the opportunity and danger of the moment, which people not only see, but also define, at the moment.

This means that as much work as possible should be delegated to machines, but no more. As Einstein said, "Everything should be made as simple as possible, but no simpler." The implication is that we should be making far more use than we do of robots and teleoperation, both in low Earth orbit (LEO) and deep space; NASA should be a leader in robotics and teleoperation, not a follower. However, we should not delude ourselves by thinking that, just because it is difficult and expensive to support people, we can dispense with them. For many years the space science community has aggressively turned its back on an important opportunity for human work and supervision of assembly, test, checkout, and adjustment of spacecraft and satellites in LEO, before sending them off to do their work. It is time for more rewarding working relationships between the space science community and human spaceflight.

We simply do not now know whether people can survive and work in space (low gravity) for long enough periods to do space exploration themselves, or whether we can only send robots and teleoperators. The Space Act gives NASA the mandate, even the requirement, to find out. The obvious target for such exploration is Mars, and the obvious question is, Is a long human expedition to some destination like Mars possible and sensible, or must we do it only with robots with teleoperator supervision? If we could start again, the appropriate space station would be more like a submarine or a "construction shack" than an all- and every-purpose laboratory. The laboratory/construction shack would be built up slowly as knowledge and capabilities required. We would separate the movement of people from the movement of cargo and do more human and teleoperated assembly in space. If I could "wave a magic wand," we would have separate lift systems for humans and cargo and use much more robotics and teleoperation, reserving for people only those tasks where human intervention may be most beneficial.

These ideas are offered as a basis for development of space policy and implementation into some new directions that might provide a reasonable evolutionary path for space science and technology.



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## ON THE FUTURE OF THE SPACE PROGRAM

**Riccardo Giacconi**

The *Columbia* tragedy has forced a re-examination of the entire U.S. space program with a much more open discussion of its goal and value. There is little question regarding the value and extraordinary success of the robotic space science program of NASA. The scientific exploration of the solar system and of the universe has stunned and delighted scientists and the general public. This effort has its own goals and rationale within the overall research priorities of the nation. One could, however, articulate one concern in this matter: the need to design maintenance and servicing capabilities as an integral part of major scientific enterprises. Transportation costs have not decreased and flight opportunities have not become more abundant; thus a major instrument in orbit (for instance a telescope) should be regarded as an important capital asset. Short of this approach we can expect to see major time gaps on the order of tens of years in capabilities in each discipline. One could hope that greater efficiency in the conduct of science missions could alleviate this problem. Lastly, the suggestion that a fixed percentage of NASA's budget, and only that fixed percentage, should be dedicated to basic science research is ill-conceived. The science budget and the human exploration budget each have their own unique justifications and rationales. The NASA science budget should be seen in relation to overall basic research priorities in the nation, while the human exploration budget should be set by the support needed to achieve long-range national goals for human spaceflight.

Except for the short-term goal of a race to the Moon, no administration has chosen to articulate a long-term goal, possibly for fear of appearing too futuristic or appearing to impose large new expenditures. The net result has been to place an extraordinary focus on short-term technical developments, such as shuttle operations and space station construction, with a somewhat vague understanding that these were necessary steps toward future exploration of the solar system. It is not clear at all that in following this road we have made any real progress toward exploration of other planets in the last 30 years. This statement follows from the fact that, not having an actual plan for how to take the next step (for instance in human exploration of Mars), it is not clear at all how the current infrastructure can support future programs.

It appears that perhaps two fundamental errors were made with regard to the space shuttle and space station programs. With regard to the space shuttle, it is clear that attempting to unify the cargo-lifting capability and the delivery of crew in one reusable vehicle has led to an exceedingly complicated and vulnerable system. With regard to the space station, the focus on the International Space Station (ISS) as a platform for research rather than as an enabler of research and technology development has left us with a science program of doubtful quality and one possibly irrelevant to future solar system exploration.

The United States has the opportunity to rectify the first mistake with the transportation system with the development of a small and safe space plane or capsule that can carry astronauts and the development of heavy-lift expendable cargo systems capable of docking with the ISS or at other rendezvous points. With respect to the space station, rather than abandoning its development, restructuring the station's capabilities with an emphasis on pursuing scientific and technological research compatible with and relevant to an overall vision of future goals is the appropriate next step to take.

This author believes that our primary long-term goal should be the establishment of a small self-sustaining colony on Mars. The ISS could be the assembly point for an Earth-orbit-to-Mars-orbit ferry or a direct launch vehicle. The ISS could also be the assembly point and servicing node for any facilities at the Lagrangian points (L1 and L2) or facilities on the Moon. However, a deviation to L1, L2, or the Moon and/or asteroids could result, once again, in distracting our attention and resources from what should be our primary goal.

Mars is the most Earth-like planet in the solar system and perhaps the only one where we can obtain high leverage by utilizing in situ resources to establish a first extraterrestrial habitat. Pre-positioning infrastructure, both in Mars orbit and on the ground by automatic heavy cargo vehicles, should precede and accompany a manned Mars landing. Of course, the ability of the ISS to support such a program may



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diminish over time, but it is the opinion of this author that the ISS provides the only feasible next step to a Mars mission in the near future.

Worth a brief review is the relationship between fundamental research, such as astrophysics, and the human spaceflight program. The human program is justified independently of the scientific program and cannot be justified on the basis of science. The effort to do so distorts *both* the human exploration program *and* the scientific program. When one discusses "scientific exploration of the planets," it is remarkable how little relevance that discussion has to human spaceflight and human exploration. The study of planetary formation and evolution is as fascinating as any other scientific discipline, but should not be confused with the focused research necessary to prepare us for human exploration. Similarly, microgravity research may not be relevant to exploration, whereas the physiological effects of partial gravity are of paramount significance.

In conclusion, this author advocates the continuation of our very productive scientific exploration of the universe, and the articulation of a clear vision for the human exploration program, with the suggested primary goal of establishing a self-sustaining colony on Mars. Early technical and financial planning for this mission should be started with the aim of identifying the architecture necessary to accomplish it. The United States should proceed with an evolutionary approach based on current available technology and a foreseeable funding profile. Lastly, there should be a more careful definition of the role of the International Space Station and a transportation system, a definition that can be aligned with a newly articulated vision and architecture.

## SCIENCE AND TECHNOLOGY ISSUES IN A HUMAN SPACE EXPLORATION PROGRAM

**Noel W. Hinners**

The post-*Columbia* examination of policy issues and goals relevant to the future U.S. human spaceflight program tends to focus on destinations, means, and budgets, and many at this workshop are addressing them. Too frequently lost is rational discussion of the question of what the purpose or function is. When this is addressed, it is answered with the exploration imperative "it's in our human nature," or "we are adventurers." These rank high but suffer from an inherent inability to quantify the benefit to be derived that justifies the large budgets and the goals that may be achieved. Frequently the exploration goals include the conduct of scientific research and the construction and/or repair of science facilities by astronauts. Indeed, a previous NASA administrator, Dan Goldin, proclaimed that we would not see human exploration of Mars until there is a compelling scientific (read "life") or economic reason to so do. There is no credible economic justification on the horizon. Thus science and scientific exploration goals dominate whether the target destination be the Moon, Lagrange points, asteroids, or Mars. The attraction of a scientific rationale is evident: It is the one that can best be addressed in terms that have a convincing semblance of progress and provide a basis for going beyond a dead-ended *veni, vidi (vici?)* approach.

The role of science in a human spaceflight program requires reexamination in the light of two developments: (1) a recent NASA depiction of the human spaceflight program as "science-driven" and a capability provider and (2) significant but underutilized progress in robotic technology and information systems since the days of Apollo and the space station.

Let us look at the history of the incorporation of science in human spaceflight programs. One finds a uniformity of opinion in many documented statements over the past 40 years that *a science rationale in and of itself does not justify the expense of human spaceflight*. Yet many in the space science community recognize that *given human spaceflight, there are abundant science tasks that can be well accomplished by astronauts*, tasks that today are or were either too difficult or expensive to automate (in the context of robotic programs). These are the activities that take advantage of the powers of human observation and decision making in situ and that are worth the cost. Apollo is an example of how science can be



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incorporated successfully in human spaceflight. Apollo was a superb political, technical, and scientific achievement.

It was not, however, without a supreme effort on the part of the science community that science was adequately incorporated as an element of the Apollo program. An analogous struggle continues to this day with lesser success; the history of science utilization of the shuttle and the ISS is fraught with a low-productivity force-fit of science into the programs. The result has been a suboptimization of the science and an unnecessary added expense to human spaceflight, sometimes with little relevance to the advance of the basic goal of enabling long-duration human space exploration. The reports of the NRC Committee on Human Exploration discuss this in detail and recommend optimum ways to incorporate science into human spaceflight programs. We also suggest that an improved, narrowed focus on the legitimate goals for human space exploration and activity could result in an identification of functions and activities where the direct human presence is either required or very valuable. This reassessment could result in an immediate effect of reducing shuttle/ISS costs and freeing up funding that could be better used for defining and making progress on research directly relevant to long-duration human spaceflight.

In its 2003 Strategic Plan, NASA describes five prime enterprises: space science, Earth science, biological and physical research, aerospace technology (largely aeronautics), and education. It depicts spaceflight and aerospace technology as supporting capabilities. This distorts the argument for and hinders resolution of whither goest human space exploration: *Human space exploration must stand on its own independent merits* as an enterprise in which it is recognized that in the arena of science (excluding human long-duration flight-enabling biological/psychological science), human space exploration will depend primarily on the science enterprises to judge what science is worth the investment. The balancing act is not trivial; the historical tendency has been to load the human spaceflight program with science objectives and tasks without an independent assessment of their inherent value and without the benefit of a trade-off with robotic accomplishment (or possibly of not doing that particular science). The situation is the more difficult in that the space science establishment tends to shy away from endorsement of the science component of human spaceflight for fear of being charged with a bill they cannot support or one that might preempt well-defined and important existing science priorities.

To sharpen the debate, it is useful to pose the following question: If human spaceflight did not exist today, would one initiate it? Probably not; there simply is no political imperative such as propelled Apollo, access-to-space costs remain prohibitive, and the state of robotic exploration has progressed immensely in the interim 40 years. Indeed, even during the Apollo era the Soviets returned lunar samples robotically three times and had rovers that made traverses longer than we are planning today for Mars. These superb achievements were totally overshadowed by Apollo.

It is important to recognize that the human presence in space is the combination of synthetic environments coupled with robotic systems and that it is unproductive to continue to perpetuate the human/robot dichotomy as if the human presence were an independent possibility. The impetus must come from the human spaceflight enterprise to both use and foster robotic enhancement of human performance, including applicable parts of information technology. At the same time, the robotic exploration community should advance autonomy to achieve more productive exploration; e.g., Mars rovers can traverse no more than tens of meters per day for want of autonomy systems that are within the state of the art. The obvious public excitement over the Mars Sojourner rover is testimony to the interest that robotics can generate. A national human spaceflight program that develops and uses advanced robotic systems and artificial intelligence could attract and invigorate a new generation of young people to enter the fields of technology and science. Concurrently it would reinvigorate the aging NASA staff and excite and benefit the industrial base in this nation.



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## ON FUTURE NATIONAL SPACE POLICY
**Wesley T. Huntress, Jr.**

NASA's space science program is proceeding on an inspiring, well-managed, and productive path. My remarks here are directed principally at NASA's human spaceflight program, which is uninspiring and marching blindly into a dead end.

NASA is in fact not a science agency; it is an engineering organization engaged in a business almost foreign to government—exploration. Exploration provides no direct service to the people, cannot be quantified or justified in terms of tangible benefits, and is a discretionary activity. Yet the intangible benefits of space exploration are many and powerful; otherwise, governments would have discontinued investment long ago.

The imperative to explore is inherent in human beings. We explore to discover and expand the frontiers of human experience. We explore to understand what is beyond our current horizons and remove fear of the unknown. These are survival instincts. Human expansion into space is a continuation of the ancient human imperative to explore, exploit, and settle. Space exploration has become a part of our culture. Flying in space is part of who we are as a nation.

Any attempt to ascribe economic benefit to space exploration, particularly beyond Earth orbit, is futile in the near term. There may be long-term benefits—resources, power generation, or some other form of commerce—but these are not the imperatives for space exploration. We explore space because we choose to do so and because we are compelled by an inherent notion of manifest destiny in space. The immediate benefits of human exploration are cultural and societal. The economic benefits of scientific exploration are unpredictable but always follow.

Human exploration of space is motivated more by societal factors than it is by science. Science is the principal product of the robotic space exploration program but historically only a by-product of human exploration. Any decision on how to proceed with human space exploration will be made more on societal and less on scientific grounds. Nonetheless, when a decision is made to continue human exploration beyond Earth orbit, it will provide a tremendous opportunity for scientist-explorers and, unlike in the past, science should be a motivating force in defining human space exploration goals.

Geopolitical factors have been triggers for crucial events in the evolution of space exploration, the most famous being Apollo and, most recently, the salvation of the space station. 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 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 was. 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 the ISS are the products of NASA attempting over the decades to preserve the Apollo era of human spaceflight 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 problem is not with human spaceflight; it is with this kind of human spaceflight. The ISS is not the 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 spaceflight. 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 of space telescopes—not



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for making 90-minute trips around Earth. The whole point of leaving home is to go somewhere, not to endlessly circle the block.

Sooner or later we must have a clear destination for human spaceflight or it will not survive, and America will be much the poorer for it. A new option does not 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. The human exploration program needs to go somewhere!

I believe that the nation should adopt a long-term policy to establish a permanent presence in the solar system beyond Earth orbit and specifically to establish a human outpost on Mars by the middle of this century. A progressive, step-by-step approach should be devised for achieving this goal, one that does not require an Apollo-like spending curve and one that involves cooperation with other space-faring nations. The stepping stones in this progressive approach are intermediate destinations, such as the Sun-Earth Lagrangian Point L2, the Moon, and near-Earth asteroids, where useful scientific exploration can be carried out.

NASA's Earth-to-orbit transportation and on-orbit infrastructure should be reinvented to support these goals. The shuttle and the ISS are not on the critical path other than for conducting research on human physiology in space. The goals of the ISS should be limited and refocused to those specific purposes required to enable human exploration beyond Earth orbit. The shuttle should be retired after flying only those missions necessary to complete the ISS. Human transport to and from space, and within space, should be separated from cargo transport. New simpler, lower-risk, lower-cost, Earth-to-orbit transportation systems should be devised that will support requirements for human exploration beyond Earth orbit.

## SEVEN HABITS OF HIGHLY EFFECTIVE EXPLORATION GOALS
**Thomas D. Jones**

In response to the *Columbia* shuttle accident and subsequent investigation by the Gehman board, the administration and Congress have begun internal studies and public hearings on the future of the U.S. civil space program. Much of the discussion has focused on destinations: Where should the U.S. venture next in space? While we should decide on a destination (a physical place in the solar system to explore), the actual location is less important than our ability to explain why we are going there. In selecting a new space exploration goal, we will benefit from including specific elements common to successful exploration strategies of the past.

Here are seven characteristics of any future human exploration program that are necessary for broad and continuing support:

1. Whether we choose to go to the Moon, Mars, or the nearby asteroids, our choice of an exploration goal must answer the simple question of *why* it is vital to get there. Our new declaration of purpose in space must include a clear statement of why human beings—and specifically this nation's citizens—should invest their treasure and energies in achieving such a goal. That rationale must resonate with our citizens at the taxpayer level. "Beat the Russians to the Moon" was understood by every citizen as a highly visible demonstration of our nation's technological competence. Our goal should thus not be justified solely as a "science project" whose importance can only be explained by an obscure research community. Developing "enabling technologies" or running a "science-driven enterprise" are examples of goals that are neither well defined nor easily explained to the taxpayers. Our next challenge in space should engage citizens and reinforce their hopes for a brighter future for America.
2. To sustain long-term funding, the goal must be understood and supported by both the administration and Congress. In competing with other domestic initiatives, human (and robotic) space exploration must be seen as politically beneficial to law makers and to the executive branch.



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Our success in developing such a consensus will be directly proportional to the strength of the rationale enunciated in (1) above.

3. The goal must be supported by a simple programmatic roadmap with highly visible intermediate milestones. These concrete, incremental steps should clearly and logically enable the achievement of the final objective. These milestones provide clear evidence of progress, build momentum, and maintain support for completing the journey. "Lunar orbit test of the Apollo lander" is a good example; "building a world-class scientific laboratory in orbit" is not, because it is difficult to know exactly when one has been built. Clearly defined milestones also add confidence to budget projections for overall program achievement.

4. Demonstrate a steady build-up of space infrastructure (transportation, propellant, power, habitable space, scientific capability) during achievement of the exploration goal. Such hardware and capability will be valuable to policy makers for expanded or alternate activities. The Apollo example is instructive: Following six successful lunar landings, the only infrastructure left in place was a pair of Saturn V's, two launch pads, and a short-lived orbital workshop with no expansion capability. Our efforts to achieve our next goal should leverage other commercial, scientific, and national security opportunities.

5. Identify near-term material benefits from conducting an exploration program. For example, show how building space infrastructure will further commercial activities in orbit. Estimate the potential value of using in situ resources in place of those delivered from Earth. Explain how national security will benefit from human exploration activity. If the only benefit is an increase in knowledge, this should be clearly articulated and stated at the outset. That rationale can then be weighed against the projected costs of the program and other budget priorities.

6. Demonstrate that measurable progress can be made toward the goal within 5 years. If the program cannot deliver highly visible achievements within a single administration's term, it is unlikely to garner the political interest necessary to sustain it among other budget priorities. For example, the ISS survived cancellation only when it gained (tangential) foreign policy relevance to the last administration. Political relevance is a necessity and just as important as scientific return or technical feasibility.

7. Remember the bottom line. Any new space policy goal for the nation's civil space program should be:

- *Understandable*—The "why" of any space goal should be clear to both the taxpayer and the politician.
- *Achievable*—A roadmap with incremental milestones should show progression to greater capability and eventual success.
- *Affordable*—Make use of existing technology to achieve early progress; build momentum with small successes.
- *Valuable*—The new goal should be of clear, measurable value to the nation, spinning off benefits even as we strive to reach it.

Choosing a goal is the easy part of the problem. Sustaining the effort to achieve it is the more difficult task. Learning from our past failed efforts, and our occasional successes, will increase the likelihood that our nation's next goal in space will be a demonstrable step forward, and not an exercise in maintaining the status quo.



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## INSTITUTIONAL CHALLENGES FOR CONTINUED SPACE EXPLORATION
**Todd R. La Porte**

Much of what the workshop has been asked to consider calls out the scientific and technical promise of sustained space exploration/exploitation. We have heard a good deal about these parameters and how they might be prioritized for future efforts. In the background has been an undertone of concern about the engineering, operational, and political currents that surround our space program—now being carried forward in the face of considerable ambiguity. I turn to further sources of this ambiguity—concerns that should surely be taken into account as future directions are discussed.

This author's interests are in "the operational and regulatory surprises" that follow from policy and professional enthusiasms for technologies. For the context of the workshop this interest translates into questions about the operation of technical organizations. These questions include: What is the implication institutionally and operationally when the technologies in question are so demanding or so hazardous that trial-and-error learning no longer seems to be a confident mode of learning? Or when these technologies are so demanding that operators (regulators) and the public come to sense that in some areas, the next error may be your last trial? Asked yet another way, what is the impact on an organization when technologies are so demanding that nearly failure-free operation becomes a condition for delivering benefits of a technical system? As it turns out, organizations facing the challenges of such technologies are often able to operate "nearly failure free" for long periods of time, even as long as many decades.

For NASA (as well as a number of other public technical systems) such long-term successful operations have always been a stunning reach. This is also true for those of us studying large organizations, where Murphy's law is a general rule of thumb. The operational reach of space programs has always been "to be better than they should be, given what we know about large-scale organizations, generally." We know this operational goal is very demanding, and there is ample evidence of how difficult it is to attain this goal repeatedly across a number of hazardous technologies (Perrow, Vaughan, and others) as they are operated from one management generation to another. When one seeks answers about what it takes actually to manage large-scale systems, responsible for often highly hazardous operations on missions that imply operational stability for many years, some of the answers are unsettling; others tend to erode public confidence if they are not taken into account in program direction setting and justification. Discussions about NASA often make allusions to the need for safe and operationally reliable systems that probably demand the organizational properties I am referring to.

In the context of considering possible future directions and characteristics of the U.S. space program, the institutional requisites of space exploration continue to make remarkable demands, for they imply very-long-term institutional management of both the unmanned and manned aspects of space exploration and possibly commercial and security exploitation.

When seen from an organizational perspective—perspectives that variously color the views of political decision makers and the public—the institutional design challenge is to provide mission structure and institutional processes and incentives in such ways that they assure highly reliable operations over the very long term—perhaps up to a hundreds of years—in the context of continuously high levels of public trust and confidence.

As future directions are considered, what would be the implications for agencies and institutions—and their leaders—were attentive publics to expect them to conduct highly reliable, often very hazardous operations for the foreseeable social future? Given our interests here, "long term," in institutional terms, expands one's tacit expectations that these activities may be required for the indefinite future, perhaps a hundred years. This is a very tall design order. It should be taken into account in considering the character and tone of musings about future directions.

If highly reliable, multi-generational, and publicly trusted systems are sought, what are many of the operational and management properties implied by such a program's reach? These are outlined below. When these conditions are laid out, it is neither a pretty nor an encouraging picture. These properties include the following (see tables attached):



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I. Characteristics of highly reliable organizations (HROs)
   a. Internal processes: Strong sense of mission and operational goals, commitment to highly reliable operations, both in production and safety.
   b. Reliability-enhancing operations.
      i. Extraordinary technical competence.
      ii. Sustained, high technical performance.
      iii. Structural flexibility and redundance.
      iv. Collegial, decentralized authority patterns in the face of intense, high-tempo operational demands.
      v. Flexible decision-making processes involving operating teams.
      vi. Processes enabling continual search for improvement.
      vii. Processes that reward the discovery and reporting of error, even one's own.
   c. Organizational culture of reliability, including norms that stress the equal value of reliable production and operational safety.
   d. External "watching" elements.
      i. Strong superordinate institutional visibility in parent organization.
      ii. Strong presence of stakeholding groups.
      iii. Mechanisms for "boundary spanning" between the units and these "watchers."
      iv. Venues for credible operational information on a timely basis.

II. Characteristics associated with institutional constancy
   a. Assurance of steadfast political will.
   b. Formal goal of unswerving adherence to the spirit of the initial agreement.
   c. Strong articulation of commitments by high-status agency leaders calling on staff in achieving constancy.
   d. Clear evidence of institutional norms that nurture the persistence of comments across many generations.
   e. Vigorous external reinforcement from regulatory agencies and public watching groups.
   f. Organizational infrastructure of constancy
      i. Administrative and technical capacity to carry out constancy-assurance activities reinforced by agency rewards.
      ii. Adequate resources to ensure the transfer of requisite technical and institutional knowledge across worker and management generations.
      iii. Analytical and resource support for future impact analyses.
      iv. Capacity to detect and remedy the early onset of likely failure that threatens the future, with the assurance of remediation if failures occur.

III. Institutional trust-enhancing relationships
   a. Interaction with external parties.
   b. Early and continuing involvement of stakeholders' advisory groups with frequent contact, complete candor, and rapid, full response.
   c. Timely accomplishment of agreements unless modified through an open process established in advance.
   d. Consistent, respectful reaching out to state and community leaders and the general public to inform and consult about technical and operational aspects of agency activities.
   e. Active, periodic presence of agency leaders (e.g., being visible and accessible to citizens at important agency field sites).
   f. Unmistakable local agency and program residential presence that contributes to community affairs and pays through appropriate mechanisms its fair share of the tax burden.



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g. Assuring negotiated benefits to the community with resources to the affected host communities that are needed to detect and respond to unexpected costs.
h. Internal organizational conditions:
    i. High professional and managerial competence and discipline in meeting technically realistic schedules.
    ii. Pursuit of technical options whose consequences can be most clearly demonstrated to broad segments of the public.
    iii. Processes of self-assessment that permit the agency to get ahead of problems before they are discovered by outsiders.
    iv. Tough internal processes of reviewing and discovering actual operating activities that include stakeholders.
    v. Clear, institutionalized assignment of responsibility for protecting the efforts to sustain public trust and confidence and constancy activities.

## HUMAN SPACEFLIGHT AS AN AMERICAN PATRIMONY

**John M. Logsdon**

For at least the first 25 years of the U.S. civil space program, political leaders have been willing to allocate the resources required to carry out a program of human spaceflight for two reasons usually not publicly articulated—national power and national pride. As the United States debates the future of its space program, and particularly of its human spaceflight component, it is important to assess whether these rationales remain a sufficient basis for undertaking a risky and costly activity. It is also important to judge whether having America continuing to actively put people in space qualifies as a U.S. "patrimony"—an inheritance from earlier successes that has become part of the core U.S. culture and deserves to be continued because of its value to the nation's self-image.

In early 1958 the newly created President's Science Advisory Committee laid out four reasons for the "importance, urgency, and inevitability" of the U.S. space program. In order of priority, in PSAC's view, they were (1) "the compelling urge of man to explore . . . to go where no one has gone before," (2) "the defense objective . . . we must be prepared to use space to defend ourselves," (3) "national prestige," and (4) "new opportunities for scientific operations and experiments."

Human spaceflight has been seen by successive policy leaders as essential to achieving at least the first and third of these goals. In its full statement of national space policy, issued in January 1960, the Eisenhower Administration declared that "to the layman, manned spaceflight and exploration will represent the true conquest of outer space and hence the ultimate goal of space activities."

In the May 1961 paper that recommended to President Kennedy that he set a manned lunar landing as a national goal, NASA Administrator James Webb and Secretary of Defense Robert McNamara argued that "it is man, not merely machines, that captures the imagination of the world" and that "*this nation needs to make a positive decision to pursue space projects aimed at enhancing national prestige* [italics in original]," because such projects were "part of the battle along the fluid front of the cold war."

In 1971, as the Nixon Administration debated to continue its shrinking of NASA's human spaceflight ambitions by canceling the Apollo 16 and 17 missions, not launching Skylab, and not approving space shuttle development, Office of Management and Budget Deputy Director Caspar Weinberger told President Nixon that such decisions would confirm a belief "that our best years are behind us, that we are turning inward, . . . and voluntarily starting to give up our superpower status, and our desire to maintain world superiority." He added, "America should be able to afford something besides increased welfare . . . ." Nixon replied, "I agree with Cap." A few months later, as NASA made its best argument to the White House on why the shuttle should be approved, Administrator James Fletcher suggested that "for the U.S. not to be in space, while others do have men in space, is unthinkable, and is a position which America cannot accept."



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Finally, in December 1983 as it sought President Reagan's approval to begin developing a space station, NASA's bottom-line argument was that such a project would be "a highly visible symbol of U.S. strength."

Now, 20 years later, do these arguments still have merit, or must any future U.S. human spaceflight project be justified primarily on its instrumental merits? Has the pursuit of ambitious post-Apollo programs of human spaceflight led the United States into an expensive dead-end with respect to future projects? Or, once the many problems associated with those programs are set aside and their essential character judged, do they and the programs of the 1960s indeed form part of this country's patrimony—a foundation of accomplishment and expectations on which current decision makers should build?

## A TALE OF TWO NASAs

**Richard N. Malow**

An examination of U.S. space policy, and where it should (or should not) be headed might be helped first by an appraisal of where we have been. Let us start by taking a look at the human spaceflight side of NASA. From the time that the shuttle flew its first mission in April 1981, the United States has spent roughly $125 billion on human spaceflight. What do we have to show for it? An honest answer to that question might be "not much." That is especially true if one compares the past 25 years with the Apollo era—which achieved the remarkable success of landing 12 men on the Moon, and safely returning them to Earth. What was the biggest difference between these two eras? Simply put, the Apollo program had a real, definable, and exciting goal, while the shuttle/station era did not. The latter was not a human space program with a goal. Rather, it would be better characterized as developing a capability. And, sadly, after spending all that money, we have not met even the minimum shuttle/station capability that we were sold by NASA.

Recall that the shuttle's advantage as a reusable vehicle was to provide assured, frequent, and relatively cheap access to space. And recall that the space station was originally sold as a kind of "do all things for all communities facility." At the start, it included a "garage" for repairing satellites, a microgravity laboratory for the development of new pharmaceutical and biotechnology products, and a platform for astronomical research. Over time, much of this capability was discarded, and even the microgravity activity, for myriad reasons, has not been adequately developed. So, sadly, perhaps the best we can say about this $125 billion is that it has kept thousands of aerospace and NASA personnel employed.

But crying over "spilt milk" (albeit $125 billion worth of milk) is not very useful. What is useful, though, is to try to not make the same mistakes again. And for human spaceflight that means setting a real, definable, and exciting goal and sticking with it. What that means (as one possibility) is that we should set a goal of landing men and women on Mars by 2025 and begin to develop a permanent human presence there.

What it does not mean, for example, is spending $10 billion on a new orbital space plane (OSP), unless it is a critical element of a newly defined human space goal. And that is clearly not the case today. In fact, the OSP (or whatever name is popular this month) reflects exactly what is wrong with NASA's human spaceflight program (or lack of program). Amazingly, we have spent roughly $5 billion on at least four or five versions of an OSP, including Venture Star, and NASP, and so on. And what do we have to show for it? Sadly, once again, very little.

But perhaps the biggest irony is that if the human spaceflight folks took a few minutes to look over at their neighbors—the space science side of NASA—they would see how programs with definable, real, and exciting goals can be successful. If we take a look at the same era, 1981 to today, NASA's space science program has achieved a remarkable string of successes that have not only delivered groundbreaking science, but have also captured the imagination of the public. In fact one could argue that Voyager, Hubble, Galileo, Chandra, Pathfinder, SIRTF, and Compton are the programs that have been NASA's "lifesavers." NASA's Mars program has set a clear and simple goal by asking the following



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question: Is there any evidence of life on Mars now or in the past? If the two Mars Express missions now on their way to the red planet are successful, the effect will be measurably more exciting and scientifically useful than shuttle missions re-supplying a space station that does little more than orbit Earth every 90 minutes.

Additionally, just this past year, NASA's space science division has again set a new and even more ambitious goal—developing a nuclear power capability in space tied to a Jupiter Icy Moons mission. Is it risky? Yes, of course! Is it controversial? Yes, somewhat. But it is a real goal that importantly combines a capability development program with a science mission. The human spaceflight side of NASA has nothing remotely like this, and that is the critical problem. But the point here is not to denigrate human spaceflight. We know that it can be both exciting and useful. Seeing the last night launch of Apollo was one of the most unforgettable experiences of this writer's life. And it can be that way again, but not unless we turn an ongoing "Tower of Babel" of voices and viewgraphs into a program with a real goal. Admittedly, though, in this climate, the chances of doing that are not great. Why? Because NASA has dug itself a pretty deep hole.

First, we have a space transportation system that is both fragile and expensive. Second, we are committed to a space station program that is not only expensive, but also is lacking in excitement and has little or no recognizable benefits—especially as it has evolved over the past 5 years. And lastly, we have a NASA budget that suffers from nearly 10 years of "we can do it for less" syndrome. As deep as this hole is (and partly because the hole is so deep), there is a growing sense among some space political players that NASA cannot stay on the shuttle/station track and expect to be successful. Interestingly, much of that sense is coming from the Congress and other independent organizations such as the International Academy of Astronautics. To date, this sense has definitely not come from NASA or the White House. That may change whenever the president announces some kind of a new space policy. We will see, but one thing is certain: Nothing will change unless there is a consensus of the political leadership which fully supports a new human spaceflight program, and that will not likely happen unless the United States sets out a definable goal that catches the imagination of the public.

Each person has his or her own idea of how to best capture the imagination of the public. My own sense is that while it may be interesting to chart a path that starts with human flights to the Lagrange points and a rendezvous with an asteroid, the only goal that will capture the public's imagination is establishing a human presence on Mars. And if we pick that goal, it should not be diluted by four or five precursor missions, unless those missions are absolutely critical in achieving the Mars goal. They may be interesting, but they will also be costly, and in today's budget-deficit climate, too many precursor missions could sink the one that matters. As it did with Apollo, NASA should keep its eyes on the prize. And the prize is Mars.

To set the right course for the future, the nation should do the following:

- Set a firm date for the retirement of the space shuttle and the space station of not later than 2015.
- Do not build an orbital space plane with the principal mission of ferrying astronauts and supplies to the station and low Earth orbit.
- Set a date for the initial landing of humans on Mars that can lead to a permanent presence on the planet.
- Develop the capability to meet the above goal, including a potential robust nuclear power effort (if a permanent presence on Mars is deemed essential).
- Foster a culture for human spaceflight that is not based on a "safety trumps all" model—but rather a true exploration model where safety is important, but the loss of human life is accepted as likely.

NASA is stuck in a kind of space "catch 22." It is burdened with the millstone of a space station that sucks dollars into a low Earth orbit black hole with no end in sight. In this budget climate especially, it



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will take people who are not afraid to take risks, both political and human, if NASA is ever going to get out of this hole. It can be done, as NASA's space science program has shown. But it will never happen if all we do is patch up and extend an old, unexciting, Earth-orbiting human space program.

## THE QUEST FOR A CONTINUING HUMAN SPACEFLIGHT MISSION
**Howard E. McCurdy**

The unwillingness of government officials to commit the United States to an overarching, long-term objective has been a continuing feature of U.S. human space policy since the beginning of the space exploration era. Dwight Eisenhower, the first president to preside over space exploration, refused to approve any human flight program beyond Project Mercury and opposed the proposal to race to the Moon. Space enthusiasts credit President John F. Kennedy with establishing the first long-range goal, but archival materials suggest that he was not a devoted supporter of human spaceflight. Neither Kennedy nor President Lyndon Johnson encouraged the development of any long-range human spaceflight endeavor beyond Project Apollo. President Kennedy chose to race to the Moon less out of a commitment to extending human presence into the cosmos than as a demonstration of U.S. technological prowess. Kennedy made the decision at a time when people around the world believed that the outcome of the Cold War would be determined on the basis of technology and management, and he desired a spectacular demonstration "which promises dramatic results in which we could win."[2] Landing humans on the Moon gave an appearance of national competence at a time when human spaceflight occupied a central place within the popular culture of imagining things to come.

As the United States approached the date for the first landing on the Moon, NASA officials rolled out their long-range plan for the exploration of space, a vision contained in various internal documents dating back to the formation of the civil space agency. NASA's internal plan became the basis for the September 1969 report of the President's Space Task Group. Members of that group advanced the overall vision of space exploration that had captivated public attention for many years. They called for a large orbiting space station, an elaborate space transportation system, a lunar base, a human expedition to Mars, and a series of high-profile robotic missions that included a "Grand Tour" of the solar system and a large orbiting observatory. According to the authors of the report, a national commitment to human spaceflight would allow all of these missions to be undertaken by 1989.

Officials in the White House and Congress rejected such a broad commitment. Instead, White House officials allowed advocates of human spaceflight to select one new initiative. In essence, partisans of human spaceflight were encouraged to proceed incrementally, one step at a time, without official reference to long-term goals.

Obliged to choose between competing endeavors, NASA leaders decided to pursue a reusable space shuttle and defer its long-standing vision of an orbiting space station. One decade later, after convincing President Ronald Reagan to declare the space shuttle "fully operational," NASA officials resurrected their space station dream.[3] Anticipated completion of the space station core in 2004 provided a subsequent opportunity for the "next logical step" in NASA's unapproved long-range plan. Unfortunately, the loss of the space shuttle *Columbia* in February 2003 makes that next logical step harder to identify.

Throughout this period, efforts to establish a long-range policy for human flight encountered substantial resistance. In 1989, President George Bush challenged space advocates to establish a lunar base and prepare for a 2019 expedition to Mars. Congress refused to fund the endeavor. Caution on the political front was dictated by financial and technical difficulties in human spaceflight programs already approved. Politicians insisted that NASA officials complete existing initiatives before diverting resources

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[2] John F. Kennedy. Memorandum for Vice President, April 20, 1961.
[3] Ronald Reagan, United States Space Policy: Remarks on the Completion of the Fourth Mission of the Space Shuttle *Columbia*, July 4, 1982.



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to new endeavors. Yet the difficulties with those endeavors in large measure arose from the absence of a long-range plan.

Lacking a guiding purpose, NASA officials were obliged to build broad coalitions for new human spaceflight initiatives. The coalitions proved easier to construct than actual facilities. To win support for the space shuttle, NASA officials promised to construct a vehicle that would serve many functions. The shuttle program was designed to provide a vehicle that could transport commercial payloads, deliver military reconnaissance satellites, establish a short-duration orbital laboratory, repair and return satellites, transport civilians, increase reliability, cut the cost of spaceflight "by a factor of ten," and produce a fleet of spacecraft that would fly 500 missions over 20 years.[4] The original 1984 space station was conceived as a multi-functional facility from which astronauts could service and repair satellites, observe Earth and the heavens, conduct life science and materials research, undertake military research and development, manufacture alloys and pharmaceutical products, welcome international partners, and prepare spacecraft for missions beyond Earth orbit. The existence of multiple and often conflicting functions significantly complicated development efforts on these two initiatives and ensured that few of the functions were ever performed well.

In theory, the approval of a long-range plan for human spaceflight would provide the focus necessary to concentrate resources for near-term initiatives on a few, workable objectives. In spite of the apparent logic of this approach, however, few incentives exist for its pursuit. A recent *Houston Chronicle* poll revealed little public support for long-range endeavors such as colonies on Mars.[5] Officials in the Congress and the White House are notoriously skeptical of long-term commitments, favoring the enhanced oversight that the frequent review of small, incremental steps provides. Little money exists for a bold, new initiative. Conditions supporting the approval of a long-range plan are more favorable than they have been in many years, but historic commitment to small, successive steps remains as attractive to political leaders as the broad rationality of a long-range plan.

## SPACE POLICY AND PUBLIC DIPLOMACY

**Norman P. Neureiter**

After World War II the United States sought to assert its global leadership and achieve foreign policy goals with gestures of cooperation in the development of advanced technology. Cooperation in space became part of that effort when NASA was established. NASA was intentionally set up as a civil space organization when it was founded, with the military aspects of space left to the Defense Department. International cooperation was always intended to be a key element of its operations, though it would be based on NASA leadership of any given project.

To oversimplify, U.S. foreign policy goals are to build and sustain peaceful, constructive relations between the United States and other countries. The space program has helped to do that in different ways. In the 1960s, during the height of the Apollo program, our embassies abroad showed films of the Saturn 5 launches and the flights to the Moon. For instance, in Poland the public could attend films that played all day long and demonstrated the great technical capabilities of the United States. It was a tremendous instrument for projecting into the communist world the image of the United States as the true space leader and also for trying to build relationships with people in those countries. Over the course of the nation's progress in manned spaceflight, adding foreign astronauts to U.S. missions on the space shuttle has also helped build better relations. In Japan and Brazil, their astronauts became national heroes. One major cooperative effort drew on the space program to highlight the "détente" period with the USSR in the 1970s. It started with the signing of seven science-related agreements in 1972 at the Nixon-Brezhnev summit. One of them was the first space agreement with the Soviets, which led to the

[4] Press conference of Dr. James Fletcher and George M. Low, San Clemente Inn, California, January 5, 1972.
[5] Tony Freemantle and Mike Tolson, "Majority Wants Spaceflight Halted Until Goals Set," *Houston Chronicle*, July 20, 2003.



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joint docking project and eventually evolved into close cooperation on the ISS. Former fighter pilots, who trained to fight each other, are now cooperating as astronauts and cosmonauts in joint missions.

A new challenge is posed by the recent successful manned spaceflight by China. Many in the foreign policy community see the U.S.-China relationship as the most important bilateral relationship for the United States in the coming years. China's recent successful launch of a man into space may be based on comparatively old technology, but the Chinese will now seek to position themselves and their technical prowess as a model for the rest of the developing world. China will continue to pursue human spaceflight programs and has reportedly expressed an interest in cooperating with the United States.

The Arab world poses another challenge. The Zogby Brothers polling group recently published survey data from several Muslim nations. In Iran and a number of Arab countries, the perception of U.S. science and technology was exceptionally favorable, even when opinions of other aspects of American life and policy were very low.

Can we take advantage of China's interest in space cooperation or the Arab world's positive view of our technological capabilities to further our foreign policy and public diplomacy goals? Can the space program be an effective instrument for building newer and better relationships with those countries, unlikely as that may sound? Possibly, but using the space program as a tool for public diplomacy is hindered by two dominant elements of U.S. foreign policy today: nonproliferation of weapons of mass destruction (WMD), and homeland security, both related to the broader war on terrorism and vital for the protection of the American people. The nonproliferation issue, in particular, affects space cooperation because space activity relates to missiles that can deliver WMD. All cooperative proposals with any other country will be carefully screened for proliferation risks, and very cautious decisions will be made in the present environment.

A further issue affecting our ability to carry on effective international cooperation in science and technology involves the new visa regulations and procedures instituted after 9/11. It is affecting the entry of students, researchers, and visiting scientists to the United States. In addition to creating a negative impression among those whose visas are denied or delayed, in the long term it could also have a serious impact on U.S. research if the best and the brightest graduate students and postdoctoral researchers, who have traditionally come to the United States, choose to go to other countries where they feel more welcome. We must find the proper balance between our tradition of openness and the needs of homeland security.

The ISS is important for two reasons. First is concern about our image as a reliable international partner in major technology programs with multiple partners. Second is that our partners have made large (for them) investments over many years in the ISS, and no major decision on its fate should be made without their involvement. While it is true that the United States has had many successful international programs, we have a mixed record as a reliable partner in big, multiyear technology programs. Particularly when we are seeking to work with other nations and build global coalitions in the fight against terrorism, it is not desirable to cut off a peaceful civilian program in which the international astronaut partners have truly become national heroes in their home countries. It can do great damage to America's image as a world technology leader.

There are those who may wish to cut, in its entirety, the human spaceflight program. To do so would take away a powerful instrument for public diplomacy and international cooperation, but more importantly would project an image of technological retrenchment and retreat at a time when the Chinese are celebrating their first manned flight and announcing bold plans for the future. The image of American space leadership has been generated by manned flight. This is not the time to take such a decision, regardless of what the final resolution is for the ISS. Certainly a successful completion of the ISS on a partnership basis would be the best solution, but if that is not possible, it must be worked out together with the partners. A failure to do so could have a serious impact on future attitudes both in the United States and abroad toward big science or technology projects—which in fact will become increasingly necessary as the costs of large facilities such as particle accelerators continue to rise and exceed the capacity of any nation to build alone.



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## CONSIDERING EXPLORATION AND THE NECESSITY OF HUMANS IN SPACE

**Dava Newman**

NASA's mandate is exploration as well as to develop knowledge of the universe and the technical means to achieve exploration. The three themes highlighted herein include education, human-robotic missions, and societal opportunities. Additional attention is paid to NASA's organizational structure and the role of the International Space Station (ISS); these two topics need to be addressed in any near-term space policy if the United States is to realize any future long-term goals for space exploration. I end with statements proposing that the universe should be accessible to all and that we should never underestimate the impact of gaining new perspectives and new knowledge.

Exploration is synonymous with education; space exploration is synonymous with inspiration, motivation, excitement, dreams, discovery, imagination, and creativity. Every one of us has been touched by space exploration. We have gained vast knowledge, each and every one of us, through space exploration. Future generations, our students and children, stand to be the beneficiaries from an exhilarating, long-term space policy or the heirs of a bureaucratic, short-term space policy. The choice of endowment is ours. We should have an explicit national goal to educate the world's best mathematicians, scientists, and engineers (starting in elementary school and continuing through college). A space policy that embraces the challenges of exploration would fuel such a goal. A related issue is producing the future work force of innovators, engineers, scientists, and humanists. A long-term commitment to exploration through sound space policy will result in a highly educated and trained workforce. What motivates learners? The extreme challenges that space exploration creates.

Should humans explore space? Yes. That is what humans do—humans explore. Are robots essential to space exploration? Absolutely. The question becomes, What is the location we want to explore and how do we explore it? The answer to the second part of this question is, with human-robotic exploration missions. The location will have to be determined and, depending on what is chosen, the specific mode of human-robotic exploration may vary. We may choose humans assisted by robotic explorers (if our location is the Moon, Mars, L1, L2, moons of outer planets) or robots/probes assisted by humans who are not co-located. Humans solve problems, are creative, and bring unequalled knowledge, experience, vision, mobility, and dexterity to exploration. We might say that robots enable exploration and that "humans enable serendipity."[6] It is clear to me that a human-robotic partnership is paramount for exploration-class missions. We should discuss the symbiosis of human-machine capabilities as enablers. It is senseless to pit humans versus robots when setting policy for space exploration. We need to attain the correct balance between human-robotic capabilities to enable exploration. Finally, for human spaceflight endeavors costs must be reduced, safety must be enhanced, and risks should be minimized. More importantly, the high risk of human spaceflight for truly challenging missions (i.e., beyond low Earth orbit) should be articulated and then accepted. But acceptance relies on educating the public.

We have not had national leadership to realize space policy with long-term exploration goals in decades. NASA has a recent vision (to improve life here, to extend life to there, to find life beyond) and mission (to understand and protect our home planet, to explore the universe and search for life, to inspire the next generation of explorers . . . as only NASA can[7]) as well as 10 goals. NASA suffers from lack of executive and congressional support for the newly proposed strategic plan.

We are a global people, but very split as a global community currently. I am committed to realizing peaceful cooperation in space exploration, and I think that the United States should assume a leadership role in a global effort. The benefits to humanity would become apparent through collaborations and by inspiring and educating future generations.

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[6] Mankins, J.C., 2002, "The Exploration and Development of Space: The International Space Station and Beyond," from *Beyond the ISS: The Future of Human Spaceflight*, Advanced Programs Office, NASA, Washington, D.C.
[7] NASA Strategic Plan, NASA Headquarters, Washington, D.C., 2003.



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The Rogers Commission and the *Columbia* Accident Investigation Board reports[8,9] clearly depict NASA's organizational and management shortcomings and offer recommendations. It is fair to question if the current NASA bureaucracy is structurally capable of implementing its bold strategic vision. This author, for one, does believe that NASA and the larger community of investigators, engineers, and managers *are* intellectually capable of achieving the stated vision and mission.

The ISS is best used as a testbed for technology development, demonstrations, and applied research focused on human (and animal) performance during long-duration spaceflight. We are gaining valuable experience in operations, and the international cooperation is also a step in the right direction. Breakthrough science is possible on the ISS, and in time it will occur. However, many results may be realized in hindsight, and the speculation about such scientific results is not sufficient justification for an orbiting laboratory. An efficiently run station that serves as a stepping stone for future space exploration could be justified.

In closing, our national space policy should focus on the goal of making the universe accessible to all. Exploration provides humans a fresh perspective and new knowledge. Paraphrasing and editing Soren Kierkagaard, "to dare (explore) is to lose one's footing momentarily. To not dare (explore) is to lose oneself."[10]

## DO THE LIFE SCIENCES HAVE A SIGNIFICANT ROLE IN NASA'S RESEARCH?

**Mary Jane Osborn**

The life sciences include (1) fundamental biological processes whose development and/or function is dependent on gravity; (2) those aspects of human (and animal) physiology and behavior that are significantly affected by microgravity environments; and (3) medical science and applied biosciences that are relevant to safety considerations or necessary for long-term human survival and function in space. Research in these aspects of the life sciences should indeed be given high priority at NASA, provided that a national consensus is achieved on a national space policy that contains a real commitment to the human exploration of space.

At the present time, the U.S. commitment to human exploration of space, which for many years has been fragile at best, appears to be in mortal danger. Prospective federal budgets are unlikely to look kindly on new initiatives for NASA, such as the space plane, much less serious planning for human exploration beyond low Earth orbit. The International Space Station (ISS) was in a parlous state even before the loss of *Columbia*, and that disaster has apparently solidified a perception, correct or not, that the nation is risk-averse to the point that any activity is unacceptable if it cannot be guaranteed to be safe. In contrast, it is the adding of unnecessary and avoidable risk to inherently and necessarily risky activity that is properly unacceptable.

In this context it is difficult to argue that life sciences research should have priority in the currently feasible NASA portfolio. NASA is arguably the major player in space science, and its contributions have been spectacular both to the scientific community and the public. No such past success can be claimed for NASA biological or biomedical research. On the contrary, the relevant scientific community remains by and large skeptical, and the public indifferent. In major part the problem lies with the lack of a research platform in which sophisticated, well-controlled long-duration experiments could be mounted. In part, however, some poor programmatic choices in the past led to flight experiments that the community deemed trivial. In truth, however, much of the biomedical research relevant and necessary for prolonged spaceflight is not intrinsically attractive in spite of the hype it has sometimes received.

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[8] Presidential Commission on the Space Shuttle *Challenger* Accident (Rogers Commission Report), Government Printing Office, Washington, D.C., June 6, 1986.
[9] *Columbia* Accident Investigation Board Report, Volume I, August, 2003.
[10] Personal communication and thanks to M.L Cummings.



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It is obvious that NASA's biomedical research program will not solve the problem of human aging, or cancer, or neurological disease. And the probability that NASA-sponsored research will lead to any major advancement in knowledge in these areas is, in my opinion, low. However, as has been stated repeatedly by NRC and NASA advisory committees, continued biomedical research is essential to understanding and ameliorating problems that may limit astronauts' health, well-being, and performance during prolonged spaceflight, and NASA's program should be directed explicitly to this goal. If, then, human exploration of space is consigned to a future that is never realized, the rationale for NASA's overall biomedical research program essentially evaporates.

Is there, however, important biological research that can only be done in the context of spaceflight and, specifically, long-duration spaceflight, even if human exploration beyond low Earth orbit is not a goal for the civil space program? The answer is certainly yes. There are a limited set of biological phenomena and processes that are fundamentally dependent on gravity. These include gravitropism in plants and in animals, development and maintenance of weight-bearing bone and muscle, and development and function of the neurovestibular system. The mechanisms whereby these processes sense and respond to gravity are not well understood, and critical mechanistic studies can only be carried out under conditions in which gravity is an independent variable and long-duration experiments are possible that allow long-term developmental studies. And will such studies require human presence rather than purely robotic control? Yes. Unlike purely observational research, biological experiments very frequently require changes in protocol as experiments progress—the human eye to recognize the need to modify and the human mind and hand to solve the problem or grab the opportunity.

Hence the need for the ISS, and, parenthetically, the need for trained scientific investigators to carry out experiments. However, if the ISS is to be maintained as a platform for relatively long duration experiments in the biological and physical sciences, then problems of astronaut health and performance in- and post-flight reemerge as issues of major concern, and NASA's biomedical research program regains immediate relevance and priority. Whether the station can in the relatively near term be brought into condition to function as a laboratory for sophisticated biological and biomedical research is another question. Even before the present hiatus, reduction and delays in necessary facilities have significantly compromised the research potential of the station and the interest of the relevant investigator community to committing to station experiments.

The present outlook is bleak, but there is reason for optimism. For myself, human exploration of the solar system is as necessary and as valuable for this age as was the circumnavigation of the globe and the exploration of the continents in previous ages, endeavors that were, if less costly in money, infinitely more costly in lives.

## THE FIVE FRONTIERS OF SPACE

**Edward C. Stone**

NASA was formed at the dawn of the Space Age as part of the U.S. investment to create a space-faring capability. Today the United States is indeed a space-faring nation, and it is hard to imagine a future in which it does not remain so. Even if there was no longer a NASA, we would continue to develop and deploy more advanced global positioning, communications, weather, reconnaissance, and defense systems in space.

Given that the United States is and will be a space-faring nation, what is the role of NASA in space today? Although the Space Age began 46 years ago, it is still the newest realm of human activity. There remains much to learn. A primary role for NASA is to expand the frontiers of this new realm in order to foster increasing activity and broader involvement. Expanding the frontiers of space also serves the national interest by providing opportunities for international partnerships.

There are five frontiers to this new realm of human activity:

1. The physical frontier—going where robotic systems or humans have not been.



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2. The knowledge frontier—discovering and understanding natural phenomena.
3. The engineering/technology frontier—developing the innovative engineering and technology required to expand the other frontiers.
4. The human frontier—addressing the physiological, psychological, and other aspects of effective human activity in space.
5. The applications frontier—developing and demonstrating new uses of space.

These frontiers are immense, so choices must be made. Among the criteria for such choices is the extent to which a program or project significantly expands one or more of these frontiers, thereby contributing to the achievement of a long-term goal.

The actual rate of learning or pushing the frontiers is another important measure of the value of individual programs. This is an important criterion for choosing a program. It is also important in deciding to discontinue an activity when the important questions have been answered and the rate of learning has become only incremental or is no longer commensurate with the cost and risk.

In general, space science has long-range goals and roadmaps that are periodically revisited in the light of new knowledge, new capabilities, expected rate of learning, and estimated cost and risk. It also has processes for identifying the best ideas for addressing those goals. Therefore the following focuses on human spaceflight.

The human exploration of Mars would clearly expand the physical frontier for human spaceflight and could serve as a long-range goal in determining the value of specific investments in the human spaceflight program. With proper planning and preparation, the human exploration of Mars would also expand the science frontier. This should be an international goal with a general time frame but not a commitment to a specific date.

Sending humans to Mars would require significantly expanding the engineering/technology and the human frontiers while continuing the scientific exploration of Mars with precursor robotic missions. In the near term this suggests that the human frontier should be a high priority for the International Space Station. The capabilities and use of the ISS should be optimized to achieve timely and significant progress in understanding the most important factors affecting human effectiveness and safety during long exposures in space. There will also be opportunities for the ISS to contribute to the science and applications frontiers.

One of the challenges for human spaceflight is choosing programs that will significantly increase the rate of learning associated with expanding the frontiers critical to human spaceflight so that it is commensurate with the investment and the risk. An effective way to increase the rate of learning is to proceed with a series of smaller steps rather than with the occasional, much larger step represented by a single system designed to address many different and often competing objectives. Each step should focus on an aspect of the engineering/technology or human frontier that is crucial to making a human mission to Mars feasible, affordable, and safe. The exact steps will evolve as we learn, but the overall direction will be guided by the long-term goal of the human exploration of Mars.

Expanding the frontiers means learning by going new places and trying new things. Doing what has not been done before will entail risk, but that will be acceptable if we are learning what is critical to expanding the frontiers, rather than only incrementally improving what we already know and do. That does not mean, however, that institutionally driven risks are acceptable.

Addressing challenging engineering/technology issues on reasonable time scales (e.g., 5 years) will motivate students and attract the talented workforce needed to tackle hard problems. This is important because there are now many more challenging opportunities in engineering and science than there were at the beginning of the Space Age. As a result, there is much more competition for the brightest and best, and the human spaceflight program must offer a higher rate of learning to attract a new generation of technical staff.

Experience with the space science program also suggests that if the human spaceflight program was structured to produce more learning, additional funding would follow because the value to the long-range goal of human presence on Mars would be apparent and the progress visible. The challenge for the



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human spaceflight program in the next two decades is to take the steps on the frontiers of space that will make human exploration of Mars not just a dream but inevitable.

## CONSIDERING A RATIONALE FOR THE U.S. SPACE PROGRAM
**James R. Thompson**

How should one weigh the interactions between national security, military, and civilian efforts in space? The goals may differ substantially, but the technology derived benefits all. The most evident examples are in launch vehicle technology, global positioning, and remote sensing. NASA is in a position to drive new technologies and their applications. Over the last decade, NASA's contributions have become muted and less meaningful due to internal problems and cost issues related to poor program execution. Obvious examples are *Columbia*, space station growth, and the "faster, cheaper, better" mantra. The country is being deprived of the technology benefits of a healthy NASA. One example is NASA's aeronautics program, particularly research into hypersonics. NASA's goals should be defined by imagination and should push the limits of achievement, not operate a shuttle system for the one-hundredth time or continue to add to a space station of dubious return.

Will space become an economic center of gravity? The answer is probably not. Space is already a budding economic contributor, however, through satellite services in the form of TV broadcasting, global positioning, weather forecasting, and others.

What are the contributions of space activities to U.S. foreign policy objectives? Space can be a powerful messenger communicating the capabilities and power of U.S. technology and will. Today, our message can be seen as one of confusion and weakness, as discussed above—a grounded shuttle program, a deteriorating space station, and so on. We should be very careful in setting new initiatives that can be unrealistic and poorly executed. Our national priorities are focused elsewhere. The money is probably not there. We should not rush into an orbital space plane program. We should take whatever time is required and get it right, if we do it at all.

## AMERICA'S FIVE SPACE PROGRAMS
**Albert C. Wheelon**

The U.S. space program has five quite distinct and separate components. They speak to different national needs and are funded separately: (1) the National Reconnaissance Program, (2) military space programs, (3) commercial space programs, (4) unmanned science programs at NASA, and (5) the NASA manned space program. To plan the future of one component, it is necessary to understand the other four and where they are headed. This abstract discusses the five components briefly together with their cross-couplings. As a matter of national policy, all programs were once committed to exclusive use of the shuttle as their launch vehicle. That policy has been discarded in the wake of shuttle accidents and unsustainable launch cost increases. Moreover, the first four components have concluded—for valid technical reasons—that manned participation in their missions is not only unnecessary but also undesirable. The result is that NASA's manned space program now rides exclusively on the shuttle and space station, which in turn must provide all of its financial support. As the shuttle fleet ages and losses are incurred, it is time to plan the future of this component as a freestanding activity. A new grand challenge is needed to harness our nation's imagination and capabilities. Some suggestions are presented below and an important role for the national academies identified.

The space era began with the Soviet launch of Sputnik in October 1957 and was followed by a string of other Soviet firsts in space. The first response by the United States was creation of the CORONA reconnaissance satellite program at the Central Intelligence Agency in 1959. NASA was created thereafter in 1958 with its defining challenge presented by President Kennedy in May 1961. There is often a tendency to confuse NASA's human spaceflight programs with the full portfolio of the nation's



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activities in space. In fact, NASA's human spaceflight efforts are one of five separate programs that in total define the nation's activities in space. These five activities include the following:

1. National Reconnaissance Program (approximately $8 billion in 2003),
2. Other military space programs (approximately $8.5 billion in 2003),
3. Commercial programs (for example, expenditures on communications satellites; approximately $7.5 billion in 2003),
4. NASA's Earth and space science program (approximately $5 billion in 2003), and
5. NASA's human spaceflight program (approximately $7 billion in 2003).

It is valuable to review the cross-couplings among the five programs and areas where the National Academies can influence them.

The National Reconnaissance Program (NRP) is arguably the most consistently successful component of our space efforts. It was certainly the most influential element of our strategic posture during four decades of the Cold War. It has enjoyed clear and sustained policy support plus the consistent commitment of adequate resources to meet them. An executive committee has met regularly to give the National Reconnaissance Office (NRO) policy guidance for both ongoing and new programs. It is composed of the director of Central Intelligence, the deputy secretary of defense, and a White House official (sometimes the president's science advisor). American presidents have been involved in key decisions, both to proceed with new programs and to suspend others (e.g., real-time system, CORONA, and the SAMOS cancellation). The first CORONA film was recovered 18 months after President Eisenhower gave the program its initial go-ahead. This was followed by 145 successful flights spread over 12 years (167 capsules), then by two successful second-generation systems, and the present near-real-time system. The National Reconnaissance Program also fielded families of satellites in low Earth orbit and synchronous orbit to intercept communications and telemetry signals. The NRP had enjoyed unusual privacy and flexibility until 1992 when it became a public institution. The NRP has had four important connections to manned activities:

- Manned Orbital Laboratory Program: Its primary mission was reconnaissance, but camera stability was thwarted by human presence (terminated in 1969).
- An NRO program and its contractor team provided the spacecraft and camera foundation for the Hubble Space Telescope program.
- NRO programs were committed to an exclusive reliance on shuttle launchings prior to the *Challenger* loss.
- The shuttle bay size and payload requirements were set by NRO spacecraft.
- Scientists and engineers were crucial in starting and guiding these programs, but the Academies have played no organizing role.

Military space programs began unsteadily before 1957 with SAMOS but were followed by two magnificent successes. One is a series of missile-warning (infrared) satellites in geostationary orbit. These became the second most important stabilizing element in the Cold War, behind only the CORONA satellites. Second is the Global Positioning System, which has produced a most important benefit to society—even greater than communication satellites. By contrast, military communication satellite programs began slowly—the Advent collapse in 1962 shook the confidence of the Department of Defense (DOD). The DOD decision to support Comsat and Intelsat with its traffic was an important decision. The enormous potential of the private band at 7 and 8 GHz was finally exploited. In addition, mobile services at UHF bands are extraordinarily useful for worldwide deployment of Army, Navy, and Air Force units. Military programs also suffered from an exclusive commitment to the Space Transportation System (i.e., the space shuttle), but they are now firmly committed to unmanned missions and expendable launchers because the STS orbit is wrong, its duration too short, its cost too great, and its launches too



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uncertain in view of the *Challenger* and *Columbia* disasters. The DOD is now unwilling to become entangled again. The National Academies can help advise next steps, when requested.

When describing commercial space activities, the primary exemplar is communication satellites. These programs began with the AT&T low-altitude system, Telsat, in 1962, and then with Hughes's synchronous demonstration of Syncom in 1963. The Comsat Act of 1962 established Comsat and Intelsat as monopoly providers, thereby limiting AT&T' s role in satellite communications. Comsat and Intelsat adopted a geosynchronous solution and went on to fund almost all communication satellite technology developments. Vigorous communications satellite programs began in 1970 and flowered until the mid-1990s. NASA played a useful early role in this technology development with demonstration flights (like the Applications Technology Satellite series) but withdrew in favor of Intelsat in 1973. The space shuttle rescued and returned two Hughes HS-376 spacecraft in 1984 and repaired one of the Navy's Leased Satellite (Leasat) spacecraft in 1985. However, these satellites were insured and could have been replaced in a timely manner without shuttle retrieval. Operators of communication satellites were shaken by the *Challenger* loss in 1986 and the subsequent decision to bump commercial spacecraft from the shuttle launch manifests. These customers shifted to the French Arianespace launch vehicle, as well as Chinese and Russian rockets, for access to space.

Communications satellites have been slowed more recently by deregulation, undermining Intelsat's role as a customer for spacecraft and a supporter of communications satellite technology, the extraordinary and unwarranted installation of fiber-optic cables, foolhardy system investments like Iridium (which caused a $4 billion loss to Motorola), and the proliferation of cell phone services. Satellite television remains competitive with cable TV, but there is a good deal of excess spacecraft capacity in orbit and in factories. Spacecraft are becoming a commodity—with decisions being driven by market forces and competition. Frankly, there are few ways in which the National Academies can influence these business decisions that are made primarily by MBAs rather than engineers.

NASA's science programs have led the world in exploring our solar system and the universe, yet it seems like they have always been a poor cousin to human exploration initiatives. There is still so much that can be done in the space and Earth sciences. In space science, most of this is best done with robotic missions because

- A human's presence unavoidably disrupts the measurements,
- Humans impose a short-duration limit on such missions,
- Humans cannot go to the orbits usually required, and
- Humans add a large overhead cost to the program for safety.

Although Hubble was designed to be serviced by astronauts, it probably could have been replaced with new spacecraft for about the same cost. One should notice that the basic NRO spacecraft from which Hubble was derived (i.e., 2.4-m aperture class) were replaced regularly, rather than being serviced and modified in orbit.

The four great observatories have now been launched, and a golden age of astronomy is upon us. A number of ground-based telescopes with 10-m apertures have been deployed and are operating at optical and infrared wavelengths. With adaptive optics, they produce resolution comparable to that obtained with Hubble but with greater light-gathering capability. With a 30-m aperture, the California Extremely Large Telescope (CELT) will provide 10 times the light gathering of the Keck Telescope. There is a need for optical interferometers on the ground and in space to see distant planets. The Academies have played a vital role in guiding the space and Earth science programs at NASA.

NASA's human program has a unique history. The Mercury and Gemini programs demonstrated U.S. ability to respond quickly to the Russian challenge in space. The Apollo program reestablished U.S. technological superiority, which has subsequently been reconfirmed by (1) PCs and software, (2) high-tech weapons, and (3) biotechnology. There is no need today to repeat the Apollo demonstration of U.S. technological prowess. The end of Apollo represented a turning point, as we went from trying to achieve



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a specific goal to simply creating useful capabilities. Support for a large scale next-step did not exist. President Nixon would only approve the shuttle, while the space station had to wait for the Reagan Administration. NASA sought to make the shuttle the centerpiece of the entire space program and aggressively sought a monopoly grant to carry all U.S. spacecraft into orbit. To this end, NASA designed the shuttle to meet everyone's requirements (i.e., bay size and payload to meet NRO needs). To enforce this monopoly, NASA began closing production lines for Delta, Atlas-Centaur, and Titan in 1984. This decision was appealed in 1985 to President Reagan, who directed that 10 additional Titans be purchased to backstop the NRO programs, despite objections from NASA and its congressional allies

NASA generated an economic model in 1972 that promised shuttle launches for $10 million by projecting launch rates that would rise from 6 to 60 per year in 3 years. The reality is quite different: 6 flights a year for $600 million each. NASA further argued that the country would need 600 shuttle flights between 1980 and 1991, although this was soon reduced to 165. NASA promised a reliability of one loss in 10,000 launches; the actual ratio is 1/50. In 1977 NASA persuaded sympathetic defense officials to adopt a policy that all NRO and military spacecraft fly exclusively on the space shuttle. To launch spacecraft into high-inclination orbits the Air Force also agreed to build a shuttle facility on the West Coast at a cost to the Air Force of $3 billion. The merging of spacecraft lifting and manned piloting necessarily increased the risk to astronauts and increased the cost to military missions. The diverse requirements of so many users pulled the shuttle design in too many directions and was responsible in part for driving the development cost form $5 billion to $40 billion.

Most missions were not destined for the shuttle's low orbit near the equator and needed to be lifted much higher or flung out of Earth's gravity entirely. The problem was that no funds remained to develop the additional rocket stages that were required to reach higher speeds and altitudes. NASA then persuaded McDonnell-Douglas to develop with its own funds the Pam A and Pam D stages, with a promise of future business. NASA also persuaded the Air Force to build the Inertial Upper Stage (IUS) to take DOD payloads to high orbits. To meet all the DOD mission requirements, IUS launch costs rose from $2 million to $80 million, representing the enormous penalty of building a common stage to serve all users. In 1985, the country was on a course to launch all its spacecraft with the shuttle, and the production lines for alternate launch vehicles were almost closed down. The United States was about to learn a cruel lesson.

On January 28, 1986, *Challenger* exploded, and with it the policy of putting all our eggs in one basket. The shuttle would be grounded for 2.5 years to make it safe for operation. The 10 additional Titans approved by Reagan kept the NRO and military payloads flying. The Air Force promptly increased the Titan order from 10 to 23 and vowed never again to become dependent on NASA's launch vehicle programs. The then-completed shuttle launch facility in California was mothballed and abandoned. NASA canceled its own plan to carry the hydrogen-oxygen Centaur stage in the shuttle bay after *Challenger*. Commercial customers were dropped from the manifest and told to fend for themselves. This caused major economic harm and resulted in the move of these payloads to the French, Russian, and Chinese vehicles. As time went on, the production lines for Delta and Atlas Centaur came back to life. They then continued their steady performance improvements. NASA was left with a machine designed to do all things, but few customers. With this reality, the space station became vital to the shuttle's survival. It became the raison d'etre for the shuttle because it was needed to build, man, and re-supply it.

The space shuttle and space station have since become Siamese twins. However, a compelling case for the space station has yet to be established. Certainly it is not justified on the basis of science. One could argue that both the shuttle and the space station are being pursued primarily to keep our human spaceflight capability alive—this is the right thing to do. If we were to disband the human spaceflight institution, it would be very difficult to reconstitute it. However, both programs took another blow when *Columbia* disintegrated during reentry. Like the *Challenger* accident, this accident raised serious questions about NASA's ability to establish and maintain the technical discipline needed to fly the shuttle reliably. They also highlighted its extraordinary complexity—a complexity that is a legacy of the original



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attempt to serve all users with a single machine. In thinking about what comes after the shuttle, let us see if we can articulate all of the issues that lie before us.

If our only need is to support the space station, we can do so without the space shuttle. We can carry building materials and supplies to the station using standard rockets fitted with docking modules. These rockets need not be human-rated. Astronauts can be carried up and back in special crew capsules (like Soyuz) on human-rated rockets. This is the strategy the Russians proved out long ago for their own successful space stations. If this approach is adopted, we need not and should not replace the shuttle. The question is rather, How do we implement this two-pronged strategy?

We probably do not need very much new technology to carry astronauts up and down. After all, we have been sending capsules into space and retrieving them since 1960, some with men, most with film. We know how to do this job reliably using symmetrical reentry vehicles that dissipate heat by ablation. This is the technology that was used in Mercury, Gemini, Apollo, and the NRO programs. Yet this approach does not provide a compelling case for the manned spaceflight program as we know it today. To put it differently, if the American people want a challenging and exciting program, the space station plus shuttle is not it. To use a movie analogy, it is more like a day-time soap opera than "Gone with the Wind."

The country can respond to another grand challenge, as it once did to the Apollo Moon mission. But when we will be ready to do so is an important question to ask. At the moment, our country is preoccupied with remaking the Middle East and fighting terrorism. One should ask what qualifies as a grand challenge. Certainly Mars, or one of its moons, or the intriguing moons of Jupiter are exciting challenges. We may be able to do such missions by assembling a transfer vehicle in Earth orbit, using the original Saturn V as the primary lifter. Perhaps we need a much larger rocket to reach interplanetary trajectories in a single launch, or maybe we need to develop entirely new types of propulsion for such journeys. We certainly need to know a lot about astronaut survivability. There are evidently a great many scientific and engineering studies to be done before a specific mission is chosen and an implementation plan selected. Those are tasks that the Academies are richly endowed to examine.

It is the judgment of this author that the scientific and engineering community can best support the manned space program by thinking hard about the grand challenges, not fine-tuning the existing program.



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