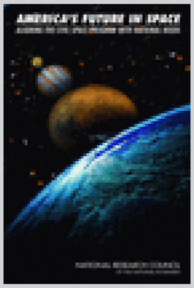

America's Future in Space: Aligning the Civil Space Program with National Needs

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AMERICA'S FUTURE IN SPACE
ALIGNING THE CIVIL SPACE PROGRAM WITH NATIONAL NEEDS

Committee on the Rationale and Goals of the U.S. Civil Space Program

Space Studies Board

Aeronautics and Space Engineering Board

Division on Engineering and Physical Sciences
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[1] Major General Bolden became NASA administrator on July 17, 2009, after writing and review of this report was completed.

Preface

Civil space activities have blossomed over the 50 years since President Eisenhower authorized an Earth satellite program as part of the International Geophysical Year. The civil space program now includes important components in the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), the Federal Aviation Administration (FAA), numerous other federal departments and agencies, academia, and private and commercial entities. A substantial national security space program preceded the civil space program and has continued to be developed concurrently in support of U.S. military and intelligence-gathering activities.

Formal policies to guide the civil space program have been established over the same period via executive orders and via legislation built on the 1958 NASA Enabling Act and other congressional directions for executive branch departments and agencies. This guidance has included continued emphasis on federal support for scientific research; development and operation of advanced space technologies and systems; establishment of a U.S. space operations infrastructure and industrial base; application of space technology to measurements of Earth and its environment and for the provision of other societal benefits; exploration of outer space; and the utilization of space activities in support of U.S. commercial, educational, and foreign-policy objectives. Major policy decisions have led to commitments to the Apollo program for human exploration of the Moon, the space shuttle and International Space Station programs for human spaceflight, the Viking and Voyager planetary missions, the Great Observatories program, Mission to Planet Earth, and the 2004 vision for human and robotic space exploration.

As civil space policies and programs have evolved, the geopolitical environment has changed dramatically. Although the U.S. space program was originally driven in large part by competition with the Soviet Union, the nation now finds itself in a post-Cold War world in which many nations have established, or are aspiring to develop, independent space capabilities. Furthermore, in the United States and globally, discoveries from developments in the first 50 years of the space age have led to an explosion of scientific and engineering knowledge and practical applications of space technology. Space activities now play critical roles in commerce, government, and science, and indeed the pervasiveness of space capabilities in the everyday lives of individual citizens is so encompassing that things we take for granted would not be possible without space technology. Federal responsibility for civil space activities now reaches across many federal agencies. For several decades, the private sector has also been developing, fielding, and expanding the commercial use of space-based technology and systems. Such private sector activities have enhanced our lives and provided capabilities for both people and commercial enterprises that could not have been dreamed of a few decades ago. Private sector space activities are likely to continue to expand beneficially in the decades ahead.

Recognizing the new national and international context for space activities, the National Research Council established the Committee on the Rationale and Goals of the U.S. Civil Space Program (see Appendix A for biographies of committee members) and charged it to prepare a report to advise the nation on key goals and critical issues in 21st-century U.S. civil space policy.[1] The committee was asked to do the following:

- Identify overarching goals that are important for our national interest.
- Identify issues that are critically important to achieving these goals and ensuring the future progress of the U.S. civil space program.
- Recommend actions to address unresolved issues.
- Explore a possible long-term future for U.S. civil space activities that is built upon lessons learned and past successes; is based on realistic expectations of future resources; and is credible scientifically, technically, and politically.[2]

During the course of its study, the committee heard from representatives of the Department of Defense, the FAA, NASA, NOAA, and the U.S. House of Representatives Subcommittee on Space and Aeronautics and from experts in areas such as space policy, journalism and public education, Earth science and applications, human space exploration, advanced technology development, commercial space, and national security. See Appendix C for the full agendas of

[1] The committee considered "civil space" to include all government, commercial, academic, and private space activities not directly intended for military or intelligence use. The committee did not include NASA's aeronautics program as an element of civil space. An extended discussion of this definition appears in Chapter 1.

[2] See Appendix B for the full statement of task for this study.

the committee's meetings. In addition, the committee invited comments and suggestions on topics relevant to its charge from the general public and from many nongovernment organizations. See Appendix D for a summary of the committee's outreach efforts and for highlights of responses from the public.

This report presents the study committee's conclusions, recommendations, and supporting material. In responding to its charge, the committee sought to provide a long-term, strategic perspective that frames a vision for civil space activities that can endure for many years. Consequently, this report does not address nearer-term issues that confront U.S. space activities other than to provide a long-term context in which more tactical decisions might be made.

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 (NRC'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 participation in the review of this report:

James G. Anderson, Harvard University,
Charles F. Bolden, Jr., U.S. Marine Corps (retired), Jack and Panther, LLC,[1]
Franklin R. Chang Diaz, Ad Astra Rocket Company,
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David Goldston, Harvard University,
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John M. Klineberg, Space Systems/Loral (retired),
Ivett A. Leyva, Air Force Research Laboratory,
Richard A. McCray, University of Colorado,
Howard E. McCurdy, American University,
Irwin I. Shapiro, Harvard-Smithsonian Center for Astrophysics,

[1] Major General Bolden became NASA administrator on July 17, 2009, after writing and review of this report was completed.

Alton D. Slay, Slay Enterprises Inc., and
Derek Webber, Spaceport Associates.

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 Peter M. Banks, Astrolabe Venture Partners. Appointed by the NRC, he 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 authoring committee and the institution.

Contents

Summary

From its inception in 1958, much of the U.S. space program was driven by opportunities to serve national interests in a geopolitical environment heavily colored by Cold War threats and fears. Originally, the true potential of space activities was largely speculative. In the ensuing decades, however, early expectations for discovery and technological accomplishment have been richly exceeded. Without a doubt, the first 50 years of the space age have been transformative. Astronauts have stood on Earth's moon while millions watched. Commercial communications and remote sensing satellites have become part of the basic infrastructure of the world. Satellites support worldwide communications, providing a critical backbone for commerce—carrying billions of global financial transactions daily, for example. Direct broadcasting beams television signals into homes globally, delivering images that bring unprecedented awareness of events occurring throughout the world. Military global positioning satellites provide ubiquitous signals that support a stunning variety of services, from assisting in the navigation of civilian airplanes, shipping, and automobiles to transmitting timing signals that enable cell phone and power grid switching. Remote sensing satellites obtain high-resolution images of Earth's surface, available now on the Internet for people worldwide to view and use, and provide critical information to monitor changes in our climate and their effects.

Our understanding of every aspect of the cosmos has been profoundly altered, and in the view of many, we stand once again at the brink of a new era. Space observations have mapped the remnant radiation from the Big Bang that began our universe. We have discovered that the expansion of the universe continues to accelerate, driven by a force that we do not yet understand, and that there are large amounts of matter in the universe that we cannot yet observe. We have seen galaxies forming at the beginning of the universe and stars forming in our own galaxy. We have explored the wonders that abound in our solar system and have found locations where life might have occurred or might even now be present. We have discovered planets around other stars, so many that it is ever more likely that there are other Earths comparable to our own.

What will the next 50 years bring? Today we live in a globalized world of societies and nations characterized by intertwined economies, trade commitments, and international security agreements. Mutual dependencies are much more pervasive and important than ever before. Many of the pressing problems that now require our best efforts to understand and resolve—from terrorism to climate change to demand for energy—are also global in nature and must be addressed through mutual worldwide action. In the judgment of the Committee on the Rationale and Goals of the U.S. Civil Space Program, the ability to operate from, through, and in space will be a key component of potential solutions to 21st-century challenges. As it has before, with the necessary alignment to achieve clearly articulated national priorities, the U.S. civil space[1] program can serve the nation effectively in this new and demanding environment.

In its initial discussions, the committee concluded that debates about the direction of the civil space program have too often focused on addressing near-term problems and issues without first putting those issues in the context of how a disciplined space program can serve larger national imperatives. In the committee's view, characterizing the top-level goals of the civil space program and the connection between those goals and broad national priorities is necessary as a foundation on which the nation (both now and in the future) can devise sustainable solutions to nearer-term issues. Therefore, the committee focused on the long-term, strategic value of the U.S. civil space program, and its report does not address nearer-term issues that affect the conduct of U.S. space activities other than to provide a context in which more tactical decisions might be made.

The national priorities that informed the committee's thinking include ensuring national security, providing clean and affordable energy, protecting the environment now and for future generations, educating an engaged citizenry and a capable workforce for the 21st century, sustaining global economic competitiveness, and working internationally to build a safer, more sustainable world. A common element across all these urgent priorities is the significant part that research and development can play in solving problems and advancing the national enterprise in each area. Instruments in space have documented an accelerating decline in arctic sea ice; mapped the circulation of the world's oceans; enabled the creation of quantitative three-dimensional data sets to improve the quality of hurricane forecasting; and created new tools to address a host of agricultural, coastal, and urban resource management problems, to cite only a few examples.

[1] The committee considered "civil space" to include all government, commercial, academic, and private space activities not directly intended for military or intelligence use.

Such capabilities demonstrate what can be achieved when technologically challenging space problems stimulate innovation that leads to long-term advances with applications beyond the space sector. Civil space activities are central to the R&D enterprise of the nation, often in a transformational way, and thus present powerful opportunities to help address major national objectives.

Observations from space offering unique capabilities for global environmental and land-use monitoring are essential to informed decision making about energy production and climate change policies, and they help provide the understanding required for wise management. The high visibility of space activities attracts students' attention to science, technology, and mathematics, and space activities are an exciting focus for teaching those subjects. Commercial space-related ventures now figure significantly in global economic competitiveness, and, while government investments to stimulate the nation's fragile economy will have short-term impacts, R&D investments can be counted on to make longer-term sustainable contributions to the nation's economic strength. As has countless times proved the case, research in and from space will continue to lead to important future, and not always currently predictable, benefits that hold the promise of progress toward realizing U.S. as well as shared international goals.

The committee's overall conclusion is that a preeminent U.S. civil space program with strengths and capabilities aligned for tackling widely acknowledged national challenges—environmental, economic, and strategic—is a national imperative today, and will continue to grow in importance in the future.

GOALS FOR THE CIVIL SPACE PROGRAM

Structured and supported to match multiple responsibilities in serving key national objectives, the U.S. civil space program should be preeminent in the sense that it can influence, by example, nations' use of space. To be a strategic leader in a globalized world requires that the United States have a civil space program whose breadth, competence, and level of accomplishment ensure that U.S. leadership is demonstrated, accepted, and welcomed.

The committee identified six strategic goals that it regards as basic for guiding program choices and resources planning for U.S. civil space activities. The goals all serve the national interest, and steady progress in achieving each of them is necessary.

- *To reestablish leadership for the protection of Earth and its inhabitants through the use of space research and technology*. The key global perspective enabled by space observations is critical to monitoring climate change and testing climate models, managing Earth resources, and mitigating risks associated with natural phenomena such as severe weather and asteroids.
- *To sustain U.S. leadership in science by seeking knowledge of the universe and searching for life beyond Earth*. Space offers a multitude of critical opportuni-

ties, unavailable in Earth-based laboratories, to extend our knowledge of the local and distant universe and to search for life beyond Earth.

- *To expand the frontiers of human activities in space*. Human spaceflight continues to challenge technology, utilize unique human capabilities, bring global prestige, and excite the public's imagination. Space provides almost limitless opportunities for extending the human experience to new frontiers.
- *To provide technological, economic, and societal benefits that contribute solutions to the nation's most pressing problems.* Space activities provide economic opportunities, stimulate innovation, and support services that improve the quality of life. U.S. economic competitiveness is directly affected by our ability to perform in this sector and the many sectors enabled and supported by space activities.
- *To inspire current and future generations*. U.S. civil space activities, built on a legacy of spectacular achievements, should continue to inspire the public and also serve to attract future generations of scientists and engineers.
- *To enhance U.S. global strategic leadership through leadership in civil space activities*. Because of the growing strategic importance of space, all nations that aspire to global political and economic leadership in the 21st century are increasing their space-faring capabilities. Continued U.S. global leadership is tied to continued U.S. leadership in space.

FOUNDATIONAL ELEMENTS

To contribute to realizing critical national objectives, including those just listed, the U.S. space program, both the civil and the national security components, must have a strong foundation and adequate resources. While the breadth of the civil space program has grown, there is also a sense that the program has been unfocused, with corresponding impacts on the organizations and institutions that support it. The United States can no longer pursue space activities on the assumption of its unchallengeable dominance—as evidenced by the view of other nations that the United States is not the only, or in some cases even the best, option for space partnerships. U.S. leadership in space activities and their capacity to serve urgent national needs must be based on preeminent technical capabilities; ingenuity, entrepreneurialism, and a willingness to take risks; and recognition of mutual interdependencies. The time has come to reassess, and, in some cases, reinvent the institutions, workforce, infrastructure, and technology base for U.S. space activities.

The committee identified four foundational elements critical to a purposeful, effective, strategic U.S. space program, without which U.S. space efforts will lack robustness, realism, sustainability, and affordability.

1. *Coordinated national strategies*—implementing national space policy coherently across all civilian agencies in support of national needs and priori-

ties and aligning attention to shared interests of civil and national security space activities;

2. *A competent technical workforce*—sufficient in size, talent, and experience to address difficult and pressing challenges;

3. *An effectively sized and structured infrastructure*—realizing synergy from the public and private sectors and from international partnerships; and

4. *A priority investment in technology and innovation*—strengthening and sustaining the U.S. capacity to meet national needs through transformational advances.

Efforts to establish each of these elements to ensure a strong foundation for the nation's civil space program must overcome several impediments. The issues include a loss of focus on national imperatives, overly constrained resources, inadequate coordination across the federal government, missed opportunities to transition roles from government-led to private-sector-provided services, obstacles to international cooperation, weakened institutional partnerships, and lack of emphasis on advanced technology development programs. Awareness of such issues—and not an effort to resolve specific instances—guided the committee in its development of recommendations to NASA, NOAA, and the federal government at the highest levels.

RECOMMENDATIONS

The committee found that, in spite of their promise and utility, components of the civil space program are not always aligned to fully capitalize on opportunities to serve the larger national interest. Decisions about civil space priorities, strategies, and programs, and the resources to achieve them, are not always made with a conscious view toward their linkages to broader national interests. Accordingly, the committee recommends as follows:

1. *Addressing national imperatives*. Emphasis should be placed on aligning space program capabilities with current high-priority national imperatives, including those where space is not traditionally considered. The U.S. civil space program has long demonstrated a capacity to effectively serve U.S. national interests.

Recommendation 1 provides a broad policy basis on which the committee's subsequent specific recommendations rest. The recommendations that follow address a set of actions, all of which are necessary to strengthen the U.S. civil space program and reinforce or enhance the contributions of civil space activities to broader national objectives.

2. *Climate and environmental monitoring.* NASA and NOAA should lead the formation of an international satellite-observing architecture capable of monitor-

ing global climate change and its consequences and support the research needed to interpret and understand the data in time for meaningful policy decisions by

a. Reversing the deterioration of the U.S. Earth observation infrastructure;

b. Developing and implementing a plan for achieving and sustaining global Earth observations;

c. Working with the international community to develop an integrated database for sensor information from all Earth-monitoring satellites;

d. Aggressively pursuing technology development for future high-priority Earth observation missions; and

e. Actively planning for transitions to continue demonstrably useful research observations on a sustained, or operational, basis.

3. *Scientific inquiry*. NASA, in cooperation with other agencies and international partners, should continue to lead a program of scientific exploration and discovery that

a. Seizes opportunities to advance understanding of Earth, the objects of the solar system, including the Sun, and the vast universe beyond;

b. Includes searches for evidence of life beyond Earth;

c. Contributes to understanding how the universe works, who we are, where we came from, and what is the destiny of our star—the Sun—our solar system, and the universe, and of the physical laws that govern them; and

d. Is guided by peer review, advisory committees, and the priorities articulated by the science communities in their strategic planning reports, such as the NRC's decadal surveys.[2]

4. *Advanced space technology*. NASA should revitalize its advanced technology development program by establishing a Defense Advanced Research Projects Agency (DARPA)-like organization within NASA as a priority mission area to support preeminent civil, national security (if dual-use), and commercial space programs. The resulting program should

a. Be organizationally independent of major development programs;

b. Serve all civil space customers, including the commercial sector;

c. Conduct an extensive assessment of the current state and potential of civil space technology; and

d. Conduct cutting-edge fundamental research in support of the nation's space technology base.

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[2] The NRC decadal surveys have been widely used by the scientific community and by program decision makers because they (a) present explicit, consensus priorities for the most important, potentially revolutionary science that should be undertaken within the span of a decade; (b) develop priorities for future investments in research facilities, space missions, and/or supporting programs; (c) rank competing opportunities and ideas and clearly indicate which ones are of higher or lower priority in terms of the timing, risk, and cost of their implementation; and (d) make the difficult adverse decisions about other meritorious ideas that cannot be accommodated within realistically available resources.

5. *International cooperation*. The government, under White House leadership, should pursue international cooperation in space proactively as a means to advance U.S. strategic leadership and meet national and mutual international goals by

a. Expanding international partnerships in studies of global change;

b. Leading an effort in which the United States and other major spacefaring nations cooperate to develop rules for a robust space operating regime that ensures that space becomes a more productive global commons for science, commerce, and other activities;

c. Rationalizing export controls so as to ensure ongoing prevention of inappropriate transfer of sensitive technologies to adversaries while eliminating barriers to international cooperation and commerce that do not contribute effectively to national security;

d. Expanding international partnerships in the use of the International Space Station (ISS);

e. Continuing international cooperation in scientific research and human space exploration;

f. Engaging the nations of the developing world in educating and training their citizens to take advantage of space technology for sustainable development; and

g. Supporting the interchange of international scholars and students.

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

a. Setting challenging objectives that advance the frontier, scientific and technological understanding, and the state of the art;

b. Establishing clear goals for each step in a sequence of human spaceflight missions beyond low Earth orbit that will develop techniques and hardware that can be used in a next step further outward;

c. Focusing use of the ISS on advancing capabilities for human space exploration;

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

National space policy too often has been implemented in a stovepipe fashion that makes it difficult to recognize connections between space activities and pressing national challenges. Often, senior policy makers with broad portfolios have not been able to take the time to consider the space program in the broader national context. Rather, policies have been translated into programs by setting budget levels and then expecting agencies to manage to those budgets. The committee believes that the process of aligning roles and responsibilities for space activities, making resource commitments, and coordinating across departments and agencies needs to be carried out at a sufficiently high level so that decisions are made from the perspective of addressing the larger national issues whose resolution space activities can help achieve. How this process is accomplished might change from administration to administration, but the need for an approach that will elevate attention to the proper level remains essential.

7. *Organizing to meet national needs.* The President of the United States should task senior executive-branch officials to align agency and department strategies; identify gaps or shortfalls in policy coverage, policy implementation, and resource allocation; and identify new opportunities for space-based endeavors that will help to address the goals of both the U.S. civil and national security space programs.

The effort should include the Assistant to the President for National Security Affairs and the Assistant to the President for Science and Technology, and should consider the following elements:

a. Coordinating budgetary guidance across federal departments and agencies involved in space activities;

b. Coordinating responsibility and accountability for resource allocations for common services and/or infrastructure;

c. Coordinating responsibility and accountability for stimulating, nurturing, and sustaining a robust space industrial base, including the commercial space industry;

d. Coordinating responsibility and accountability for initiatives to recruit and develop a competent aerospace workforce of sufficient size and talent, anticipating future needs;

e. Identifying, developing, and coordinating initiatives to address long-range technological needs for future programs;

f. Identifying, developing, and coordinating initiatives to establish and strengthen international space relationships;

g. Harmonizing the roles and responsibilities of federal agencies to eliminate gaps and unnecessary duplication in the nation's space portfolio; and

h. Regularly reviewing coordinated national space strategies and their success in implementing overall national space policy.

1

From Sputnik and Apollo to Today's Globalized Environment

For many, the National Aeronautics and Space Administration (NASA) fulfilled the task set for it by President Kennedy when Neil Armstrong and Buzz Aldrin unfurled the U.S. flag on the surface of the Moon and returned safely to Earth in late July 1969. In the 40 years since, memories of Apollo, buoyed by achievements such as the first space shuttle flights, the launch and later repair of the immensely useful and long-lived Hubble Space Telescope, and the successful Mars rover missions, among others, have helped to sustain the space program's strong appeal both in the United States and internationally. While its breadth has grown, however, the U.S. civil space program has also in many ways become unfocused and out of touch with important needs of the taxpayers that support it.

The cornerstone of the nation's civil space policy is the National Aeronautics and Space Act of 1958. Passed largely as a response to the 1957 launch of Sputnik and in recognition of scientific proposals for U.S. participation in the International Geophysical Year, the act established NASA, and presented the new agency with a broad set of objectives, including the expansion of human knowledge, the development and operation of space vehicles, the long-range studies of potential benefits to be gained from space activities, interagency and international cooperation, and the preservation of the U.S. preeminent position in aeronautics and space. NASA has been extraordinarily successful in making progress toward those goals, which today remain as compelling and appropriate as ever.

Throughout the space age, strategic global considerations have provided the primary context for U.S. space activities. The primary rationale for the signature accomplishment of the civil space program, the Apollo Moon landings, was to prove to the world the superiority of American technology and innovation and, by inference, American society. Today, both the civil space program and the nation at large are considering significant reforms and policy innovations as the nation faces a series of complex challenges related to ensuring national security, providing clean and affordable energy, protecting the environment, meeting 21st-century needs for education, sustaining global economic competitiveness, and promoting beneficial international relations. Awareness is widespread that the time has come to reassess and, in some cases, reinvent and refocus national institutions. In a time of substantial rearrangement of budgets and of national priorities, when once again objectives rather than process dominate the debate over resource allocation, it is the conclusion of the committee that the U.S. civil space program is an essential national resource with the potential to substantially address pressing national needs.

In this context, and responding to its charge, the committee sought to address the top-level goals of the civil space program and the connection between those goals and broad national priorities. Therefore, the committee focused on the long-term, strategic value of a U.S. civil space program, and the report does not address nearer-term issues that affect the conduct of U.S. space activities other than to provide a context in which more tactical decisions might be made.

EVOLVING SPACE POLICY IN A NEW GLOBAL ENVIRONMENT

In December 1990, the report of the Advisory Committee on the Future of the U.S. Space Program[1] recognized the effect of the fall of communism on the civil space program. The report recommended that space science should become the high-priority NASA program and that two mission-oriented programs—Mission to Planet Earth and Mission from Planet Earth—should share second priority. By the dawn of the new millennium, there was no single, dominant rationale for the space program, and in particular for the human spaceflight program. NASA remained generally popular with the public, but few knew much about what the agency was doing or what its goals were. The Columbia accident in February 2003 was the catalyst for a new space exploration policy (the Vision for Space Exploration) that attempted to bring policy clarity to the broader space exploration program. NASA was directed to reorient its activities and today is preparing to extend the sphere of human activity beyond the International Space Station and low Earth orbit, starting with a return to the Moon. Congress supported the new exploration vision in the NASA Authorization Acts of 2005 and 2008, but emphasized that NASA has vital, independently important responsibilities in aeronautics, Earth science, and space science in addition to human spaceflight.

The world today is characterized by intertwined economies and transnational benefits to enjoy but also serious transnational problems to confront, from terrorism to global economic crisis to climate change. Mutual dependencies coexist with national and commercial competition and rivalries.

[1] Report of the Advisory Committee on the Future of the U.S. Space Program, December 1990.

Political considerations, domestic and foreign, continue to play a key role in civil space. Even in today's multipolar and increasingly interconnected world, the global competitiveness of the U.S. aerospace industry has been significantly hindered by what are generally acknowledged to be outdated and oftentimes counterproductive International Traffic in Arms Regulations.[2] Further, which countries the United States chooses to partner with in space is influenced by foreign policy considerations. National security considerations regularly prevail over desires for international scientific collaborations.

The United States can no longer base the foreign policy aspects of space activities on the assumption of being the first choice for global partnerships based on its unchallengeable dominance. We are no longer in a position to control the space technology that is available and is increasingly being developed in other nations. As a result, the United States is no longer the only, or in some cases even the best, option for countries interested in space partnerships. Rather, as with other aspects of globalization, U.S. leadership in space activities must be based on the competitiveness of our capabilities; the attractiveness of our ingenuity, entrepreneurialism, and willingness to take risks; and our recognition of mutual interdependencies.

The scientific context also is quite different today from what it was even a decade ago. The growing realization that Earth's climate is changing and that human actions are likely largely responsible for those variations[3] is altering perceptions of the planet on which we live and heightening the importance of monitoring Earth's properties and understanding the processes that govern them. Recent astronomical discoveries (e.g., of extrasolar planets and dark energy) are overturning the established view of the universe. Similarly, observations by the Mars rovers and orbiters suggest that Mars may have been able to harbor life at some time in its history and, thus, may provide a new perspective on life as we know it. Communications and remote sensing satellites, largely originated through investments by NASA, have become viable commercial activities. Building on early successes, the capacity of the space program to contribute solutions to important issues of national interest has broadened even as the initial narrow geopolitical imperative for the program waned.

Although the national perception of the space program to a large extent harkens back to the legacy of Apollo, the committee argues in this report that the U.S. civil space program has evolved to become essential to our national welfare and is strategically vital to the United States.

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[2] See National Research Council, *Beyond "Fortress America": National Security Controls on Science and Technology in a Globalized World,* The National Academies Press, 2009, and "Briefing of the Working Group on the Health of the U.S. Space Industrial Base and the Impact of Export Controls," CSIS, Feb. 2008, available at http://www.csis.org/media/csis/pubs/021908_csis_spaceindustryitar_final.pdf.

[3] Intergovernmental Panel on Climate Change, *Climate Change 2007, IPCC Fourth Assessment Report, Summary for Policy Makers,* 2007; available at http://www.ipcc.ch.

A civil space program that is focused on creating knowledge and proving new and innovative ideas can build on the legacy of the nation's great research and development push during the Apollo era while better responding to the nation's needs today. Basic scientific research in space will plant the seeds of another generation of knowledge-based growth. Incubating new technologies for space activities, demonstrating their utility, and disseminating them broadly, will help spur the innovation and economic growth on which U.S. leadership must now be based.

THE U.S. CIVIL SPACE PROGRAM

For the purposes of this study, civil space includes all government, commercial, academic, and private space activities not directly intended for national security use by the military or intelligence communities. The interrelationships between civil and military space are complex. Civil and military space technology, and the underlying scientific and industrial base, have supported each other since the beginning of the space age, and the dual-use nature of space technology makes robust technology innovation critical to both civil and national security space efforts. The dual-use nature of space technology also, however, makes it very difficult to separate civil and national security space by system or function. For example, an imaging spacecraft can be used to make commercial maps, to manage disaster relief, or to select targets for precision strikes. Therefore, this report's definition of civil space relies on intended use and participants, rather than on capabilities.

The United States, by policy and legislation, developed and maintains separate space sectors. Most other space-faring states do not distinguish between the two, but justify funding for specific space systems based on satisfying multiple needs, both civil and security. There are numerous areas of coordination between the U.S. civil and national security sectors—launch range operations, space surveillance, weather satellite constellation, Global Positioning System signal structure, component standardization, and more—and both sectors use the same U.S. industrial base and workforce. However, from the very beginning of the space age, U.S. presidents and Congress felt that keeping national security and civil space activities separate was sufficiently important to justify the expense of a certain amount of duplication and inefficiency.

The federal civil space program has grown beyond a single government agency focused on putting humans in space and now also encompasses programs in multiple agencies. The National Oceanic and Atmospheric Administration (NOAA) and the Department of Defense (DOD) are major users of space assets and the Departments of Interior, Agriculture, and Homeland Security as well as the National Science Foundation and numerous other organizations are important beneficiaries. The U.S. civil space program is instrumental in addressing a wide variety of problems—from long-term climate change to finding the fastest route for local emergency responders in the United States and around the world—and it provides an effective means to influence progress and economic opportunity on a worldwide scale. NOAA operates a constellation of weather, climate, and environmental monitoring satellites. The Department of Transportation is responsible for regulating and promoting a commercial space sector, now including space tourism. The Federal Communications Commission licenses orbital positions and spectrum use by commercial satellites and advocates for U.S. commercial space in international forums. Many federal agencies rely on data gathered by both government and commercial spacecraft.

Civil space includes research at universities and nonprofit institutes, which provide ideas, build scientific experiments, interpret results, and educate and inspire the next-generation workforce.

Commercial communications and remote sensing satellites have become an essential component of the basic infrastructure of the world. Satellites support worldwide communications, providing a critical backbone for daily commerce—carrying billions of global financial transactions, for example. Direct broadcasting brings television signals into homes globally, delivering the images that bring awareness, unprecedented in human history, of events that are occurring throughout the world. The military global positioning satellites provide ubiquitous signals that support a stunning variety of functions, from assisting in the navigation of civilian airplanes and shipping, and allowing individuals to find their way in automobiles, to transmitting timing signals that enable cell phone and power grid switching, as well as conducting geographically dispersed scientific experiments—all simultaneously. Remote sensing satellites obtain high-resolution images from around the world, available now on the Internet. Other commercial space activities are nascent but hold the promise of new industries that will exploit the opportunities in space.

Civil space participants abroad include governments and commercial activities in the European Space Agency (and a number of individual European countries, particularly France, Germany, Italy, and the United Kingdom), Canada, Japan, Russia, South Korea, India, China, Iran, Israel, and Brazil. Sometimes, much to the consternation of the United States, the dual-use nature of the technology makes it difficult to distinguish civil space activities from those of potential value to military space activities, complicating potential cooperative opportunities in space, commercial transactions with U.S. aerospace companies, and foreign relations in general.

Private space enthusiasm has evolved into an astounding constellation of activities. Amateur astronomers track satellites, and some discover comets and other objects and observe transient phenomena. Space artists, popular broadcast programs and film, and print and electronic media articles broaden the reach of data collected. Full Web access to data and images from exploration spacecraft has built a large public community. Privately funded entrepreneurs have begun to test concepts for a space tourism industry, and privately funded prize competitions are engaging the American entrepreneurial spirit in new space activities.

Civil space activities have evolved to have a depth and breadth that are now essential to our national welfare and culture and are strategically vital to the United States.

Given the background summarized earlier and the committee's adopted definition of civil space activities, the remainder of this report will outline the committee's conclusions. The next chapter presents the principal rationales and top-level goals for civil space activities and discusses how those goals will make important long-term contributions in the national interest. The civil space program must be able to depend on a number of key resources or foundational elements to be able to achieve the goals. There also are significant challenges and impediments compromising the nation's ability to support the foundational elements and/or to reach the proposed goals. The foundational elements and the impediments, many of which cut across all of the goals, are discussed in Chapter 3. Finally, Chapter 4 presents the committee's recommendations for actions that are needed to remove the impediments, sustain the foundational elements, and permit the nation to meet the goals for civil space activities.

In responding to its charge, the committee sought to provide a long-term, strategic perspective that frames a vision for civil space activities that can endure for many years. Consequently, this report does not address nearer-term issues other than to provide a long-term context in which more tactical decisions might be made. Rather, it considers how civil space activities serve the national interest and what actions are needed at a strategic level to meet those broad objectives.

2

Goals for U.S. Civil Space Activities

The United States faces major challenges today: these include ensuring national security, providing clean and affordable energy, preventing environmental degradation, meeting 21st-century needs for education, sustaining global economic competitiveness, improving technologies for transportation and medical care, and promoting beneficial international relations. The U.S. civil space program has become a major force to be applied in meeting those challenges.

In the 21st century, civil space activities affect our daily lives and also advance the national interest in a variety of ways. Space systems play integral roles in government, business, and personal communications, positioning, and navigation; in weather monitoring and forecasting; in producing remote-sensing information for agriculture, urban land-use planning, and natural resources management; in commercial enterprises that are becoming increasingly significant factors in global economic competitiveness; and in opening new windows on humanity's place in the cosmos. While those few examples illustrate the importance of space activities in the present, space activities have crucial consequences for the nation's future as well. Because civil space endeavors are technologically and intellectually challenging, they stimulate innovation that over the long term leads to advances with applications beyond the space sector. Emphasizing the importance of research and technological innovation, the NRC report *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*[1] recommended strengthening science and engineering research "to maintain the flow of new ideas that fuel the economy, provide security, and

[1] National Research Council, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future,* The National Academies Press, Washington, D.C., 2005.

enhance the quality of life." While current government investments designed to stimulate a fragile economy can have near-term effects, investments in research in and from space can continue to lead to important future societal benefits, just as the pioneering work on concepts of electricity and magnetism in the 19th century led to uncountable (and unanticipated) applications in contemporary society.

The committee's view is that there is no single rationale for the U.S. civil space program; rather, as a significant component of the nation's R&D enterprise, the U.S. civil space program should be structured and supported to fulfill multiple responsibilities—to assist the nation in achieving its goals of exerting strategic leadership and improving the well-being of people. The U.S. civil space program should be preeminent in the sense that it can influence, by example, how nations take advantage of the opportunities afforded by space. For the United States to be a strategic leader, its civil space program must demonstrate breadth, competence, and a record of accomplishment so that U.S. leadership is accepted and welcomed.

The committee identified six major goals for U.S. civil space activities and elaborates on them in the sections that follow. All six goals serve the national interest, and steady progress toward achieving each of them will be a fundamental measure of the success of America's space program.

- *To reestablish leadership for the protection of Earth and its inhabitants through the use of space research and technology*. The key global perspective enabled by space observations is critical to monitoring climate change and testing climate models, managing Earth resources, and mitigating risks associated with natural phenomena such as severe weather and asteroids.
- *To sustain U.S. leadership in science by seeking knowledge of the universe and searching for life beyond Earth*. Space offers a multitude of critical opportunities, unavailable in Earth-based laboratories, to extend our knowledge of the local and distant universe and to search for life beyond Earth.
- *To expand the frontiers of human activities in space*. Human spaceflight continues to challenge technology, utilize unique human capabilities, bring global prestige, and excite the public's imagination. Space provides almost limitless opportunities for extending the human experience to new frontiers.
- *To provide technological, economic, and societal benefits that contribute solutions to the nation's most pressing problems.* Space activities provide economic opportunities, stimulate innovation, and support services that improve the quality of life. U.S. economic competitiveness is directly affected by our ability to perform in this sector and the many sectors enabled and supported by space activities.
- *To inspire current and future generations*. U.S. civil space activities can continue to build on a legacy of spectacular achievements to inspire our citizens and to attract future generations of scientists and engineers.

Success in advancing those five goals will result in a world-class U.S. civil space program and will serve as a basis for achieving the sixth goal, which is of particular importance:

- *To enhance U.S. global strategic leadership through leadership in civil space activities*. Because of the growing strategic importance of space, all nations that aspire to global political and economic leadership in the 21st century are developing and increasing their space-faring capabilities; continued U.S. global leadership also depends on continued U.S. leadership in space.

APPLY SPACE RESEARCH AND TECHNOLOGY TO STEWARDSHIP OF EARTH

Earth has a dynamic and fragile ecosphere (Figure 2.1). And it is home to life as we know it now and in the foreseeable future. However, humankind, by virtue of its numbers and its use of energy, now threatens the planet that supports its very existence: for example, by affecting climate and exhausting resources. Proper stewardship of Earth is thus an urgent responsibility of all people.

While everyone, from individuals to countries, must be better stewards of planet Earth, the committee believes that the United States, as a global leader, bears a special responsibility to share its expertise and the knowledge and understanding it develops on how best to care for the planet. Americans must accept a global responsibility, or risk abandoning this important moral high ground to others.

Many people live in areas that are vulnerable to severe weather, flooding, and rising sea levels. Most food production depends on the availability of rainfall, water, and adequately long growing seasons. Earth's climate is changing, and at the same time, a growing global population is increasing the stresses on natural resources. There are, of course, natural climatic changes, but the consumption of fossil fuels and resulting greenhouse gas emissions are accelerating changes that are predicted to threaten the well-being of people throughout the world.[2] The potential consequences of energy generation policy and climate change are tightly linked in ways that could further accelerate changes in the climate system.

While climate change is one of the most important global environmental problems facing the world today, other aspects of Earth stewardship also demand attention. They include improving weather forecasts; developing new tools for monitoring and managing Earth's water and land resources; and gathering information to quantify and mitigate risks from solar disturbances in space and collisions from asteroids or comets.

A goal of the U.S. civil space program is to reestablish leadership for the

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[2] See National Research Council, *Understanding and Responding to Climate Change: Highlights of National Academies Reports,* The National Academies Press, Washington, D.C., 2008.

FIGURE 2.1 Earth's oceans, land surface, cryosphere, biosphere, and atmosphere form a complex coupled system whose interactions provide a unique habitable environment. SOURCE: Courtesy of NASA.

protection of Earth and its inhabitants through the use of space research and technology.

By achieving this goal, the United States and its international partners will

- *Establish a comprehensive satellite Earth observation system, and the links to ground-based observing and information networks, that provide*

  —The data necessary to understand Earth's changing climate and to predict its regional consequences,

  —Reliable predictions of weather throughout the world, and

  —Comprehensive satellite observations of society's use of Earth and of the natural phenomena that can affect our environment;

- *Develop an understanding of asteroids and the trajectories of those that may conceivably impact Earth and plans that can be invoked in the event of an impending collision; and*
- *Establish a comprehensive research program and satellite network that allows prediction of space weather events that are dangerous or disruptive.*

Climate

Perhaps the single most important task that can be assigned to the U.S. civil space program is to provide observations of Earth from the vantage point of space. The resulting data can help scientists and policy makers to understand the physical mechanisms that control the climate system of Earth and the influence that humans are having on them, as well as to make projections and develop future climate scenarios. That Earth is warming is already established.[3] Citizens and governments now need to understand current and future regional consequences of climate change, including how precipitation patterns and habitability and productivity of specific regions can change; by how much, and when, sea levels can rise or ice sheets melt; and how alternative approaches for providing critical energy resources will relate to future climatic conditions.

Understanding the potential consequences of global warming is a challenging problem that will require comprehensive, uninterrupted satellite observations, as well as qualified scientists to interpret the data and develop predictive models. This is not a problem that the United States needs to tackle alone, nor can it. Many nations have the capability to develop remote sensing satellites, and scientists worldwide stand ready to help in developing reliable predictions of future climate conditions. Coordinated international approaches and action will depend on full participation in understanding the changes that are occurring.

Its technical and scientific resources and experience put the United States in a unique position to contribute so that all the nations of the world, including our own, can take prudent steps to protect the future of the planet. While the United States now has substantial projects and plans in place to respond to this challenge, the committee believes an even greater commitment is needed to reverse the projected decline in operational and research Earth observing missions, prepare to replace aging spacecraft, and initiate new high-priority missions.

Weather

There is a need for ever-improved weather forecasts, particularly if climate change induces severe weather events, and the difference between inconvenience and catastrophe can depend on having adequate warning. Significant progress has

[3] See National Research Council, *Understanding and Responding to Climate Change: Highlights of National Academies Reports,* The National Academies Press, Washington, D.C., 2008.

been made in improving weather forecasts, in large part as a result of more comprehensive and accurate satellite observations. But more needs to be done, such as transitioning certain proven research capabilities (e.g., vector sea-surface winds and radio occultation temperature, water vapor, and electron density soundings)[4] into operational use. Key measurements (e.g., tropospheric winds, all-weather temperature and humidity profiles, aerosol-cloud discovery, and air pollution)[5] still need to be made, and there is a need to ensure that satellites in orbit are sufficiently reliable to be able to accomplish the tasks on which people depend and that backups can quickly be brought into service when failures occur. Conducting these key measurements has been and should continue to be done in cooperation with other nations.

Managing Earth's Resources

Changes in land-use patterns, agricultural productivity, ecosystems' health, and forest resources are readily observed from space; their management can be enhanced by the use of accurate position-sensing information and diagnostic measurements taken at multiple wavelengths and as a function of time. Space observations are thus an essential component of the ability to manage the planet's resources, a source of knowledge that might protect against the effects of its most damaging forces, and a tool to verify the impact of international environmental agreements.

Near-Earth Solar System Objects

There are low-probability, very-high-consequence threats to humankind *from* space, most notably impacts by asteroids but also possibly from comets. Such events have occurred in the geological past, and although the probability of a near-term event is low, they can be expected to occur at various times in the future. Understanding the properties of near-Earth asteroids, how they are likely to behave upon impact, their locations and likelihood of collision with Earth, and options for mitigation are essential tasks for the U.S. civil space program. It would be prudent to develop a comprehensive strategy to prepare for a potential asteroid impact. This strategy would involve multiple federal and international agencies.

Space Weather

As governments and private companies increase their use of space services that are now an integral part of the economic infrastructure, users also increase

[4] National Research Council, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond,* The National Academies Press, Washington, D.C., 2008, p. 38.

[5] Ibid., pp. 313 and 322.

their vulnerability to space weather—disturbances in the upper atmosphere and the near-Earth space environment that are driven by the magnetic activity of the Sun. Space weather can temporarily or permanently disable a satellite and can also have effects at Earth's surface, such as disruptions in power grids. Because the physical processes that govern space weather are not adequately understood, there is a need for a comprehensive research program that builds on current efforts, as well as an observational network of satellites that allows adequate warning of pending space weather events.[6] Such an effort should be undertaken in cooperation with other nations.

SEEK KNOWLEDGE OF THE UNIVERSE AND SEARCH FOR LIFE BEYOND EARTH

Among the most profound questions that humankind can ask are, Where did we come from? Where are we going? Are we alone? Four hundred years after the invention of the telescope and 40 years after placement of the first telescope in space, humankind has come a long way in its quest to understand how the laws of nature reveal our origins and future in the context of the universe around us. Observations made from space have dramatically advanced what we know about the universe.

Space observations have shown that the universe began with the Big Bang 13.7 billion years ago; that it has been expanding ever since; and that the expansion is accelerating due to the repulsive force of an effect called dark energy, about which little is currently known (see Figure 2.2). The first stars and galaxies formed a few hundred million years after the Big Bang, and all galaxies are held together by the gravity of dark matter, made of yet-to-be-identified particles. The evolution of the chemical elements from primordial hot plasma to the materials that make up our world and ourselves is well understood. We can now count more than 300 planets orbiting other stars and suspect that a good fraction of the 100 billion stars within our galaxy have one or more planets.

Even more questions—including the cause of the Big Bang, the nature of dark matter and dark energy, what causes the solar activity cycle, how our solar system and other planetary systems formed, how common are habitable planets, whether there are nearby life-bearing planets, whether diverse life forms exist in the cosmos, or what is the destiny of our universe—are ripe to be answered. *A goal of the U.S. civil space program is to sustain U.S. leadership in science by seeking knowledge of the universe and searching for life beyond Earth*.

[6] Space weather takes on a new dimension as human spaceflight into deep space becomes common, because radiation from solar disturbances can injure or even kill astronauts who do not have adequate shielding and may cause long-term cancerous and noncancerous effects.

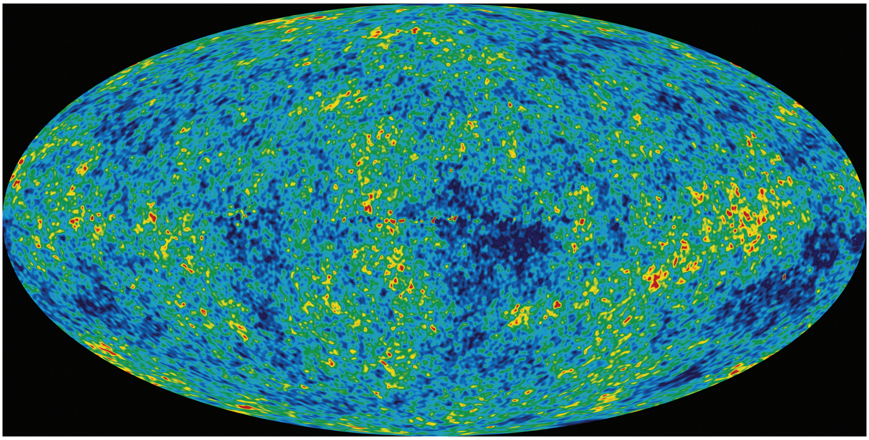


FIGURE 2.2 The Wilkinson Microwave Anisotropy Probe measured the tiny variations in the microwave echo of the Big Bang (0.001 percent). These variations provide a snapshot of the distribution of matter when the universe was 380,000 years old, before galaxies and stars were formed. Their analysis has revealed important clues about the origin of the universe and its properties today (including its shape, age, and composition). SOURCE: Courtesy of NASA.

By achieving this goal, the U.S. civil space program will

- *Dramatically extend the understanding of the origins, evolution, and destiny of our star—the Sun—our solar system, and the universe, and of the physical laws that govern them;*
- *Use unique opportunities in space to discover and understand life elsewhere and extend our understanding of life here on Earth; and*
- *Share the knowledge that enriches our understanding of our place in the universe with all of humankind.*

Understanding the Universe

If history is any guide, advances in understanding the basic physical laws of our universe ultimately have transformative practical and economic benefits. Past examples include Faraday and Maxwell's research in electricity and magnetism; Einstein's special theory of relativity (and his famous formula $E = mc^2$); and quantum theory. When quantum theory developed during the early part of the 20th century, it could not have been further removed from any practical end and, indeed, seemed like a mysterious curiosity. Today, devices based on quantum mechanics—from central processors and memory in computers to lasers and network routers that make massive information transfer possible—have enabled the information economy that is critical to our nation and our high standard of living. The economic and information potential presented by the Internet was made possible by the creation of the World Wide Web, a tool originally developed for basic research.

Space-borne observatories have proven essential to furthering modern physical understanding, as they provide a means for addressing important scientific questions in ways that cannot be done on Earth. Earth's atmosphere makes observations difficult because it absorbs most forms of electromagnetic radiation and cosmic rays, and its turbulence distorts and limits the clarity of images in the visible region of the spectrum. An Earth-based laboratory has to cope with many sources of interference to sensitive measurements. Earth-based laboratories are limited in size as well. Space, on the other hand, provides a vast, quiet laboratory largely free of the handicaps imposed by the terrestrial environment.

For instance, scientists know that Einstein's theory of general relativity is correct largely because of experiments that include accurate measurements of the motions of the Moon, Mercury, Venus, Mars, and asteroids, as well as various spacecraft. Knowledge of plasmas (essential for achieving fusion energy, not to mention the development of everyday items like fluorescent lightbulbs) would be far more limited without studies of the plasmas in our own solar system. Space-based measurements of solar energy output, activity, magnetic fields, and coronal mass ejections have contributed dramatically to an understanding of the Sun and of its profound effects on Earth. Robotic investigation of other planets and moons provides important insights into their formation and the formation and evolution of the Earth, as well as the potential for similar solar systems to have developed around other stars (see Box 2.1).

While the examples listed above have been essential to confirming and refining the breakthroughs made at the turn of the 20th century, recent advances hold the potential for further transformational increases in understanding. The ability to observe gravitational waves—ripples in spacetime itself—will open a revolutionary new window on the universe, observing many phenomena that cannot be detected directly with traditional telescopes. Observational evidence for dark matter and dark energy, for which scientists have no current explanation, shows that the laws of physics as they developed in the 20th century are not complete, and further investigation is necessary.[7]

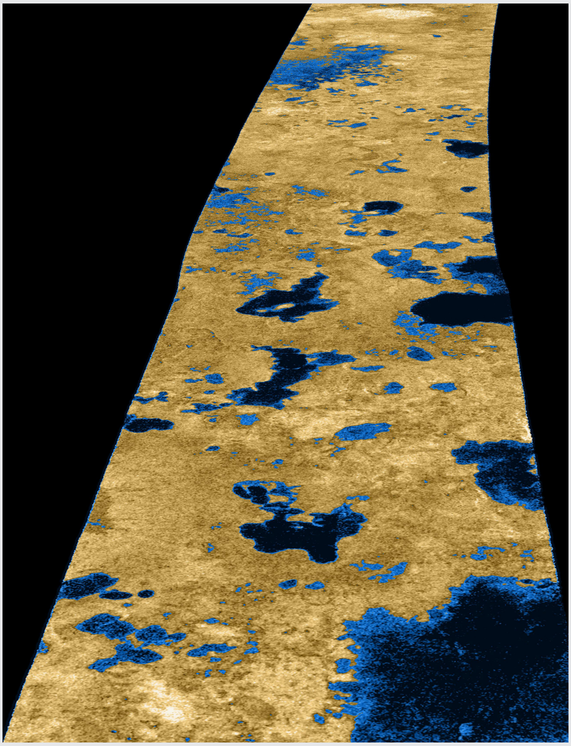
The civil space program supports research vital to answering a number of open questions about the nature of the universe and the physical laws that govern it. Although it is not clear where the advances driving future technology development will come from, the committee believes that scientific observations from space will very likely play a crucial role. Leading the world in the conduct of

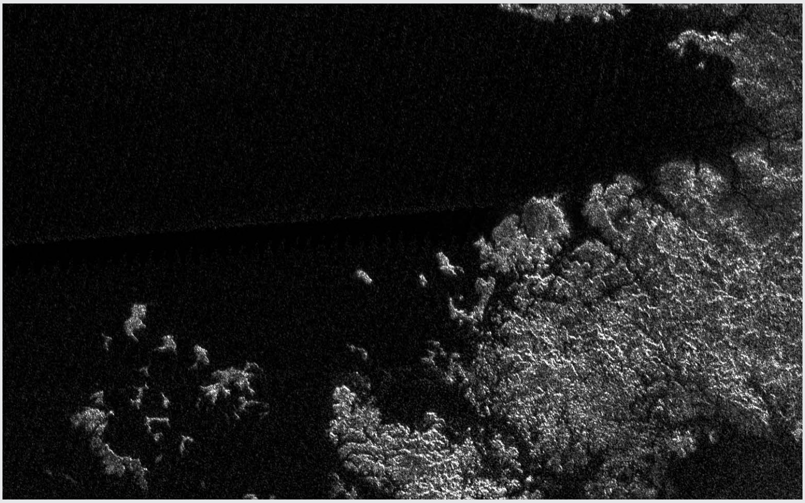
[7] National Research Council, *NASA's Beyond Einstein Program: An Architecture for Implementation,* The National Academies Press, Washington, D.C., 2007.

BOX 2.1
Seeing Titan Up Close

In the 1990s, Saturn's moon Titan appeared to be little more than a fuzzy yellow ball when observed with the best ground-based telescopes. The radar on the Cassini spacecraft penetrated Titan's dense atmosphere and revealed river valleys feeding into apparent lakes, which the spacecraft's infrared detectors then determined to be at least partly composed of liquid methane and ethane (Figure 2.1.1). Titan's "hydrological" cycle is driven by methane that plays water's role on Earth. This discovery was made possible by the ability of spacecraft to make investigations in ways impossible to achieve from Earth's surface.

FIGURE 2.1.1 Radar imaging data from the Cassini flyby of Saturn's moon Titan provides convincing evidence for large bodies of liquid on Titan. *Top:* In this false-color image, the lakes are dark blue and the surrounding terrain is tan. *Bottom:* The coastline and island groups of a large sea reveal channels, islands, bays, and other features typical of terrestrial coastlines, and the liquid, most likely a combination of methane and ethane, appears very dark to the radar instrument. SOURCE: Courtesy of NASA.





this research will help ensure that the United States remains at the technological forefront in the coming decades.

Life in the Universe

One of the great questions that space studies can illuminate is whether there is, or has been, life other than on Earth. In the words of the NRC report *The Limits of Organic Life in Planetary Systems,*[8] "It is certain that nothing would alter our view of humanity and our position in the cosmos more than the discovery of alien life." Alien life could be discovered on Mars, on moons in our solar system, or on extrasolar planets or their moons. Such a discovery would raise the question of whether non-terrestrial life is based on the same molecules that make life possible on Earth: carbon, oxygen, high-energy phosphate bonds as an energy currency, and DNA as the genetic material. If life were to be found in just one new place, it would greatly increase the likelihood that life is widespread in the universe, and that terrestrial life is thus not unique.

Finding evidence of present or past life elsewhere in this solar system would be especially exciting if samples could be returned to Earth for detailed studies. The opportunity for careful investigation of samples returned to Earth from Mars, Europa, Enceladus, and other sites that seem to offer a hope of having life is a major rationale for supporting an active space exploration program. If life is not found on such bodies, that too would provide a valuable perspective on the uniqueness of biological systems on Earth.

Searching for planets around stars other than our own Sun involves both ground- and space-based telescopes. The Hubble Space Telescope made the first image of a planet orbiting another star (see Figure 2.3), and the recently launched Kepler mission should find many planets as small as (or smaller than) Earth orbiting other stars; these planets are below the sensitivity of ground-based telescopes. The Spitzer Space Telescope has also made contributions to understanding other solar systems, via observations in the far-infrared portion of the spectrum inaccessible from Earth. Future space telescopes can use the unique vantage point of space to investigate planets beyond our solar system for signatures of life.

Enriching Our Culture

The history of the universe leading to our existence on planet Earth is written on the bodies in this solar system, the other stars and solar systems that can be detected within our galaxy, and the distant universe itself with its 100 billion visible galaxies. And clues to our cosmic destiny, from the fate of our planet and

[8] National Research Council, *The Limits of Organic Life in Planetary Systems,* The National Academies Press, Washington, D.C., 2007.

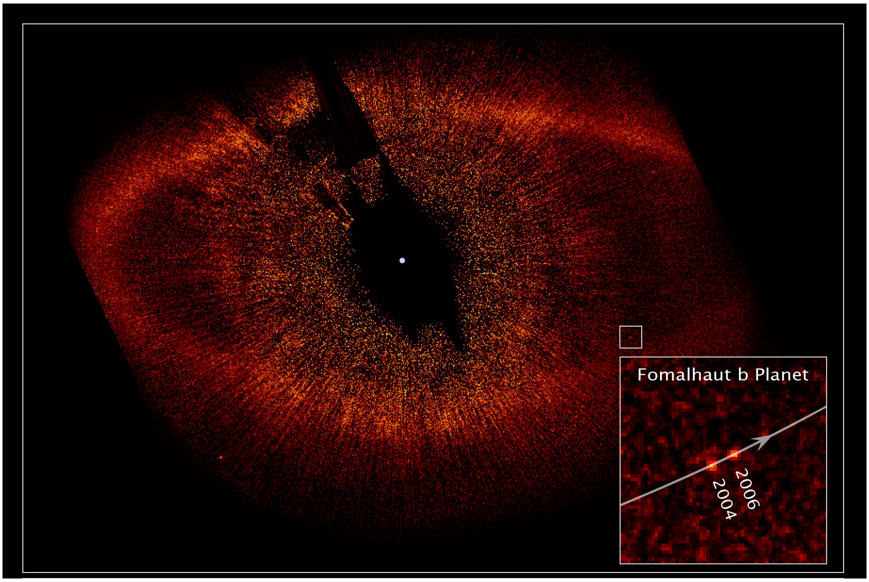


FIGURE 2.3 Formalhaut b is a Jupiter-sized planet (indicated by the white box) orbiting Formalhaut (center of image), a distant star. Its motion over a two-year interval is revealed by a Hubble Space Telescope image (inset). The planet orbits Formalhaut within its debris belt, closer to the star than the inner edge of its debris disk. SOURCE: Courtesy of NASA.

solar system to that of the universe itself, are available from observations from space and from probes that can be sent throughout the solar system.

In supporting the pursuit of this knowledge and the quest to find life elsewhere, the nation enriches its national character and inspires new generations of scientifically and technologically informed citizens—engines of growth for the national economy and for cultural enrichment.

EXPAND THE FRONTIERS OF HUMAN ACTIVITIES IN SPACE

For 50 years human spaceflight has been a national testing ground where scientific, technological, industrial, and military strength are measured and the ability to lead partners in a large effort is proven. Nations that seek to be among the leaders in human space exploration do so in order to increase their competence in technical fields and to gain the respect of others. In short, human spaceflight creates a perception of national leadership. China has thus joined the United States and Russia in demonstrating human spaceflight capability; India has announced aspirations to conduct human spaceflight; and many nations are participating in established human spaceflight programs through the provision of hardware and astronauts.

If the United States seeks to maintain its international leadership in this global environment—where the technologically capable nations of the world are participating in or aspiring to human spaceflight—then the United States must be in the forefront of human spaceflight activities and, as a result, in the governance and economic exploitation of outer space.

A goal of the U.S. civil space program is to expand the frontiers of human activities in space.

The United States associates human spaceflight with the cultural theme of the frontier, as reflected in the President's Scientific Advisory Council's 1958 rationale for space exploration, *Introduction to Outer Space,* which stated, "Since man is such an adventurous creature, there will undoubtedly come a time when he can no longer resist going out and seeing for himself." Russia, China, and other nations also connect the appeal of human spaceflight to cultural themes expressed in literature and mythology that link human spaceflight with a vision of the future.

Today, telerobotic spacecraft are the only explorers of other solar system objects. These robotic explorers continue to discover new knowledge and excite scientists, students, and the public. However, the committee believes that an entirely robotic exploration program lacks a fundamental component of the rationale for space exploration (see Box 2.2). Humans have proven effective in carrying out a variety of important roles as engineers and scientists in space (Figure 2.4).[9] It is reasonable to expect that, in this century, humans will again surpass previous limits and will visit asteroids, travel to the moons of Mars, and establish a martian base similar in scale to those in Antarctica. In the committee's view, the leadership and inspiration achieved by expanding the frontiers of human spaceflight are worth the dangers faced in such exploration; lesser objectives may not be worth the same risk.

It is not sufficient for the United States simply to have a human spaceflight program, or to judge its success based on comparisons with the capabilities or aspirations of other nations. Rather, the priorities for U.S. human spaceflight should be determined by using this criterion: which efforts have the greatest potential for, and likelihood of, producing transformative cultural, scientific,

[9] The value of human space exploration has been addressed in the NRC report *Scientific Opportunities in the Human Exploration of Space* (National Academy Press, Washington, D.C., 1994). Specific examples of past benefits from astronauts' flexibility and capacity to evaluate complex situations and adapt to unexpected situations are documented in *Where No Man Has Gone Before, A History of the Apollo Lunar Exploration Missions* (William David Compton, The NASA History Series, NASA SP-4214, NASA, Washington, D.C., 1989) and in *Assessment of Options for Extending the Lifetime of the Hubble Space Telescope* (National Research Council, The National Academies Press, Washington, D.C., 2004).

commercial, or technical outcomes. Such results could include achievement of a fundamentally new understanding or perspectives, or development of an essential new enabling capability that leads to an opportunity to visit and observe some new location. Meeting a high standard for performance can ensure that the human spaceflight program in the United States is able to be a leader among the nations with human spaceflight capability and that human spaceflight can serve the broad needs of the nation for technology development, economic growth, and inspiration—fundamental components of the nation's strategic leadership.

By achieving the goal, to expand the frontiers of human activity in space, the U.S. civil space program will

- *Put humans at the frontier in space, continually expanding the capability to move and work away from Earth, with each step enabling the next.*

Human spaceflight to explore the interesting and useful places in the solar system will necessarily be an extended activity. It will take a century or longer. And the presence of humans beyond Earth—reestablishing a sense of frontier—may be just as important as exploiting resources elsewhere in the solar system. It will take centuries more to protect against human extinction from cataclysmic events on Earth by having a permanent large human presence beyond Earth. Steps taken over many lifetimes will be required to enable people to travel where we choose. Each step, which should be achievable within a small fraction of a human lifespan, should advance the ability to take the next step in the sustained expansion of the range of human action.

International Space Station

The International Space Station (ISS) provides an important capability in preparing for an expansion of the frontiers of human activity in space. It has already enabled several important accomplishments, including learning how to construct large space structures and developing a framework for large-scale international collaboration (Figure 2.5). Future steps into space will build on the lessons learned through ISS design and construction. NASA should thus focus use of the now-completed ISS on such important technical challenges as demonstration that operationally significant quantities of water can be reused; development of the largely autonomous crew operations required for exploration of deep space; and rigorous investigation of space medical issues that could, for example, support a decision on whether a spacecraft that provides a partial-gravity environment is required for very-long-duration missions.

BOX 2.2
Balancing Robotic and Human Space Exploration

The NRC report *Science in NASA's Vision for Space Exploration*[1] addressed the question of how to make choices between robotic and human spaceflight, and the Committee on the Rationale and Goals of the U.S. Civil Space Program concurs with the conclusions of that report. The report noted that "expansion of the frontiers of human spaceflight and the robotic study of the broader universe can be complementary approaches to a larger goal" (p. 5). Robotic space missions clearly have led, and will continue to lead, to paradigm-altering discoveries about Earth, our solar system, and the universe beyond, and about fundamental physical laws. The report added that human space exploration—for example, an eventual mission to Mars—can also be transformative in changing humanity's sense of its place in the universe. Robotic space exploration and human spaceflight can be synergistic endeavors that can jointly serve to enhance U.S. leadership in science and technology.

The 2005 report provided advice on setting priorities as follows:

> The issue then is not what to pursue ultimately, but rather what to pursue first, and then how to prioritize what follows. The standard for deciding what science to select can be set by recalling the motivation for pursuing space exploration. We do so to ensure that we will continue to advance our intellectual understanding of the cosmos, including our place in it, and will continue our development as a civilization for which human spaceflight becomes routine and inevitable. The array of choices can include plans for missions and enabling science that will not be achieved for decades or longer, but it also needs to include programs from which major achievements can be expected in the nearer term (p.6).

PROVIDE TECHNOLOGICAL, ECONOMIC, AND SOCIETAL BENEFITS

The U.S. (and global) economy currently enjoys significant direct and indirect economic benefits from space activities. Space-based infrastructure supports the smooth functioning of daily life in many parts of the world and is vital to the operations of many industries. Without today's capabilities, accurate weather prediction and the resulting economic benefits would not be possible; businesses would lack reliable communications and connectivity with geographically remote parts of the world; and the growing value of ubiquitous spatial positioning and imagery would be difficult to realize. *A goal of the U.S. civil space program is to*

The report went on to recommend that decisions about what alternative opportunities to pursue should reflect consideration of two factors:

a. The critical scientific or technical breakthroughs that are possible, and in some cases necessary, and
b. How a vibrant space program can be achieved by selecting from an array of approaches to realizing potential breakthroughs across the full spectrum of NASA's goals.

The 2005 report elaborated on how these tests should be applied, saying

> For both human and robotic programs, the basic standard of achievement and impact is whether a program will lead to a fundamentally different understanding or perspective. For future missions or programs it is imperative to prioritize based on which will provide the greatest return. If a new mission or program is to proceed it must demonstrate the potential for, and likelihood of, a transformative outcome, through a more comprehensive approach, increased measurement resolution and sensitivity, or the opportunity to visit or observe some unique new location. The argument needs to be realistic and compelling because available resources always will limit the number of programs that can be supported (p.10).

The present committee fully agrees.

[1] National Research Council, *Science in NASA's Vision for Space Exploration,* The National Academies Press, Washington, D.C., 2005.

provide technological, economic, and societal benefits that contribute solutions to the nation's most pressing problems.

Economic returns from U.S. space-based activities can be classified at several different levels (Figure 2.6). The "direct" space economy of about $40 billion per year is represented by the elements of the aerospace sector devoted to the design and manufacture of space hardware utilized in global civil, military, and commercial activities; admittedly, it represents a small fraction of GDP.[10] However, this relatively small industrial base punches far above its weight economically,

[10] For additional economic data see Organization for Economic Co-operation and Development, *The Space Economy at a Glance 2007,* OECD Publishing, Paris, France, 2007.

FIGURE 2.4 An astronaut tests the Simplified Aid for Extra-Vehicular Activity Rescue system during an extravehicular activity. SOURCE: Courtesy of NASA.

as a larger pyramid of economic activity depends on the space industrial base's products.

At the next tier, and at about $80 billion per year, the satellite-based services portion of the space economy is twice the size of the space-related manufacturing sector. Satellite-based services include space-based broadcasting of television programming, satellite radio, fixed and mobile satellite telephony and data services, and space-based imagery services.

Of the satellite-based services, direct broadcast television is currently the dominant segment, representing 80 percent of space services. A space-based infrastructure provides the unique capability to distribute video programming

FIGURE 2.5 The International Space Station is a remarkable example of the impressive feats of engineering that are possible through international cooperation. SOURCE: Courtesy of NASA.

(entertainment, education, and so on) over wide areas at extremely low per-user costs. In hard-to-reach remote locations within the United States, as well as internationally, such connectivity cannot yet (and may never) be delivered over land. Communications satellites provide a level of ubiquity that can be used to respond rapidly to changing demand patterns, thus providing an "initial service" and a market where terrestrial alternatives may (or may not) develop at a later time and slower pace. The newly developing area where the value-added of satellite-based infrastructure is being demonstrated is in the delivery of broadband Internet access. Connectivity to the Internet or other large data networks in geographically remote locations is being made possible by space infrastructure.

Another element of the space services economy has been the civil and commercial delivery of satellite imagery and other observational data. Satellite imagery is used to monitor agricultural crops, determine which land is most suitable for growing a given crop, monitor fisheries and aquatic and land ecosystems, and support land-use management. Satellite information is also used to save lives and help those in need. Human rights organizations use commercial imagery to monitor and document events in places such as the Darfur region. Satellite imagery also is employed to warn communities of impending natural disasters; it thus saves lives, reduces property-related damage, and enables social action and prepared-

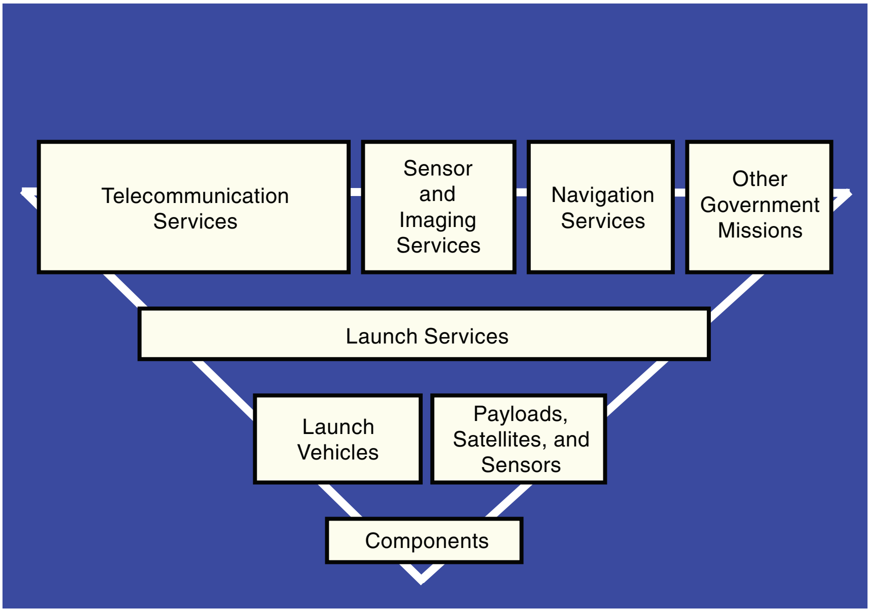


FIGURE 2.6 The pyramidal nature of the structure of the current space economy (as measured in terms of annual revenues), with a relatively narrow base of components and space hardware infrastructure supporting a much larger amount of downstream space-based services. This pyramidal structure of a larger volume of space-based services balanced on a narrower base of infrastructure and support services is likely to be a continuing feature of the space economy.

ness. After extreme-weather events, imagery is used to assess damage and enable disaster relief efforts in the affected regions, especially in more remote areas that are best monitored via satellite. This imagery allows coordinated disaster relief that keeps aid workers safer and allows them to help more people.

As mentioned in the earlier section on the stewardship of Earth, NOAA's Space Environment Center provides warnings regarding solar and geomagnetic activity. These warnings prevent economic losses from power-grid outages and satellite failures. An area of increasing concern, monitoring severe space weather events will become vital as society relies increasingly on technologies that are vulnerable to these events.

In the third and largest tier of economic activity are industries that rely on or utilize the space infrastructure that is in place. The most significant example to date is the growing use of the DOD Global Positioning System (GPS) precision navigation signals, which are being provided as a free good by the U.S. government. The precision navigation personal device market has rapidly grown into a $10 billion annual market which did not exist prior to the launch of the GPS satellites. The industry has grown from promising satellite navigation equipment in aircraft and ships, to portable devices used in vehicles and by recreational hikers, to navigation capabilities now being embedded within every next-generation cellular telephone. The applications and use of satellite-based precision navigation signals continue to proliferate and are now delivering great increases in productivity to the industries they touch. Examples include fleet tracking in the transportation industry, supply chain monitoring in the logistics industry, precision and automated agricultural practices, precise geolocation for safety and advertising purposes, and GPS surveying in the construction and mining industries.

The GPS space infrastructure plays another extremely important, but often unappreciated, role in the general modern economy—the Coordinated Universal Time distributed by GPS. Without this space-based, precise, global time stamping service the ability to coordinate and manage our telecommunications networks, Internet infrastructure, cell phone emergency 911 systems, paging networks, electrical grid and financial system (all of which rely on very good time synchronization) would be severely compromised. From that perspective, the entire economy relies on the space infrastructure.

Looking forward, there are a number of nascent markets that could develop over the coming years. For instance, segments of the public are anxious to participate in human spaceflight. Commercial human spaceflight activities began in 1990 with the flight of a Japanese journalist via Soyuz to Mir. The first of seven paid flights on Russian vehicles to the ISS occurred in 2001, and private spaceflight continued with suborbital test flights above the defined edge of space, 100 km, in 2004. Several private firms are now planning suborbital or orbital flights for paying customers in the foreseeable future. In addition, a private entity has launched its own pressurized volumes—based on purchased NASA research—that could conceivably lead to the development of privately held orbiting hotels or laboratories. While the committee acknowledges that there is inherent high risk in these ventures and that their ultimate success is not assured, of more significance and importance is the fact that there is entrepreneurial activity in the space sector and private capital being made available to invest in new space systems and capabilities.

Another key role that the space economy plays within the general economy is that of being a leading-edge consumer and driver of technology. Given the harsh and unforgiving environment of space and the difficulty of getting out of Earth's gravity well, the space industry often requires cutting-edge technology. The efforts involved in space exploration over the past half century have benefited society by pushing the limits of current technology and expanding the scientific and technological frontiers. Beginning in the 1960s, innovations such as chemical milling and high-energy metal forming, along with myriad other innovative manufacturing techniques, benefited from work on Project Mercury and subsequent programs. Recent economic trends favor workers with higher skills, and space science and aerospace research can be applied to a wide array of areas outside the space arena.

Ultimately, if humans are to travel far from Earth they will have to solve many key problems: how to generate water over extended periods of time, provide and store energy in a compact space, and grow food in a harsh environment. It is noteworthy that generating fresh water, creating efficient energy sources, and developing food sources are also among the top priorities of an ever more resource-constrained Earth. The civil space program will need to develop a deeper understanding of and countermeasures for bone loss, space radiation, and other health effects. Innovative equipment and procedures for providing medical care to astronauts could contribute to improved approaches to high-quality medical care in the United States and around the world. While the human space exploration program should not be justified based on the prospect of advances in these areas, a vigorous U.S. civil space program whose priorities are determined by assessing where it can lead to transformative scientific or technical outcomes will become a leading-edge driver and consumer of these technologies.

As stated previously, *a goal of the U.S. civil space program is to provide technological, economic, and societal benefits. By achieving this goal, the U.S. civil space program will*

- *Support and expand the capability of the private sector to help meet national needs and facilitate the development of economic opportunities that may be created in space or through the use of space systems.*
- *Create and maintain a continuous space technology pipeline and use the challenges presented by space exploration to create new technologies, contributing to the technological, scientific, and overall advancement of the nation.*

Supporting the Private Sector and the Technology Pipeline

Today's civil space program is heavily weighted toward the conduct and support of government missions, and less toward commercial enterprise. As a general principle, however, U.S. policy discourages direct government competition with private businesses. While the government must take the actions necessary to ensure its ability to successfully conduct inherently governmental missions, it should also identify and encourage opportunities to support private sector capabilities. For instance, the commercial imagery market discussed earlier has received significant support from the military and intelligence communities. This relationship helped to ensure the success of commercial imagery businesses, which in turn—paired with GPS services—has provided numerous applications benefiting the average citizen. As private sector capabilities continue to develop, the government needs to look for similar opportunities to incubate nascent markets.

A burgeoning commercial space sector requires a technology pipeline that can continually enable spacecraft to become more capable and more efficient. The government, and particularly NASA, has a role to play in developing and disseminating new technologies. The National Aeronautics and Space Act of 1958 directs NASA to preserve the role of the United States as a leader in aeronautical and space science and technology. By supporting new technologies from their infancy through to their first use on a spacecraft (the technology pipeline), NASA will enhance both government spacecraft and commercial spacecraft.[11]

As discussed in the preceding section, the government civil space program and its partners in the commercial sector have a track record of demonstrating that sound investments produce tangible products and capabilities downstream. One of the characteristics of space system developments is that many of the technologies that result from space endeavors are cross-disciplinary and multiuse. For instance, a high-efficiency solar panel developed for a NASA space telescope could be used on a NOAA climate-monitoring satellite or a commercial imagery satellite. By transferring the technology into industry, government agencies are able to leverage the capabilities of the commercial sector to share innovations and, at times, cost savings.

There are many hurdles to overcome for the commercial space sector to move beyond its infancy. They include technical challenges, such as the need to reduce the cost to launch a payload to orbit, and they also involve policy actions, such as the need for the government to know when to step back and transition roles from government-led to private sector–provided services. The committee is confident that over the long term the investments and actions necessary to develop the space economy can be significant factors in U.S. global economic competitiveness.

INSPIRE CURRENT AND FUTURE GENERATIONS

Space activities provide an opportunity to excite interest in science and engineering among young people and to promote scientific and technical literacy in the general public. Nearly 60 percent of the respondents in a recent survey were at least somewhat interested in space, and 82 percent of respondents believed that "the space program inspires young people to study science and math."[12] Responses to a questionnaire posted by the committee were similarly positive (Box 2.3). Such results indicate that the public recognizes and supports the space program's role in stimulating and exciting interest in science, technology, engineering, and mathematics (STEM).

Other evidence also supports conclusions that the public remains very interested in the civil space program. For example, the 24-hour period during which Spirit landed on Mars yielded 225 million hits to NASA's home page, and 2.6

[11] The committee discusses the current status of the government's technology development efforts in the Chapter 3 section titled "Technology and Innovation."

[12] See http://www.everettgroup.com/survey2-09/pilotsummary.pdf.

BOX 2.3
Public Responses to the Committee's Questionnaire

The committee's own Internet questionnaire drew more than 1,100 responses (for more information on the questionnaire, see Appendix D). These 1,100 responses addressed a variety of concerns, although the common theme was a belief in NASA's responsibility and potential to inspire the country. One respondent wrote:

> I view the civil space program as a vehicle for involving . . . all of America. . . . I am particularly interested in the impact of the space program on our children today. The importance of the civil space program transcends the generation gap . . . offers hope for the continued exploration of space . . . and also fosters the excitement that has always accompanied the space program. . . . We need the space program in this country and it will always bring the possibility of reaching the unknown.

Another responder added:

> NASA has been energizing the American dream for a long time . . . climaxing in 1969 when the first astronauts landed on the moon and . . . [with] the successful discoveries by the rovers Spirit and Opportunity.

million unique users visited NASA's website when Opportunity landed.[13] The Hubble Space Telescope's image archive receives at least 115 million hits a year.[14] Over the course of 10 months, 80,000 people used software on the Mars Global Surveyor website to find and mark nearly 2 million craters. The efforts of these amateur space enthusiasts produced work that was reported to be on average as good as expert crater analysis and that accomplished the equivalent of several months of dedicated work on the data.[15] Additionally, in a 2009 survey of undergraduates, NASA was among the top 10 most admired private and public sector employers.[16]

The large and enthusiastic public response to specific NASA endeavors demonstrates a curiosity about space exploration. This curiosity is an important

[13] See http://news.zdnet.co.uk/internet/0,1000000097,39147138,00.htm.
[14] See http://www.stecf.org/~rfosbury/functional/ECF-AR_06/Christensen.ppt#303,14,Slide 14.
[15] See http://www.scienceofcollaboratories.org/resources/collab.php?317.
[16] Wetfeet, *Universum's IDEAL™ Employer Rankings 2009—Undergraduate Edition,* available at http://www.wetfeet.com/universumrankings/Undergrad-2009.aspx.

first step in the learning process; as the public becomes curious about a new accomplishment, they naturally want to learn more. In this way, space activities can serve as a motivator for education and a way to capture the public's imagination. "Climate change and Earth monitoring" was the leading dominant theme of the responses to the committee's online questionnaire (for more information, see Box 2.3 and Appendix D). Both NASA and NOAA support activities dedicated to K-12 education initiatives, but the space community's efforts in space activities in and of themselves captivate the general public as well and promote further interest in learning about the science behind the missions. *A goal of the U.S. civil space program is to inspire current and future generations.*

In pursuing this goal, the U.S. civil space program will

- *Instill a sense of interest, excitement, and optimism about opportunities for scientific and technological advancements to enhance the well-being of the nation;*
- *Attract and encourage members of the next generation of the nation's technical workforce; and*
- *Create a new generation who can draw on the advantages offered by space to help solve problems on Earth, and ensure U.S. leadership, building on the solid achievements of the past 50 years of U.S. investments in space.*

Future Generations

A 2007 National Academies' study, *Rising Above the Gathering Storm: Energizing and Employing Americans for a Brighter Economic Future,* presented a comprehensive plan for the nation as it faces the problems of deficiencies in U.S. STEM education and increased global economic competition. The report recommended that the United States should "increase America's talent pool by vastly improving K-12 science and mathematics education . . . , sustain and strengthen the nation's traditional commitment to long-term basic research . . . , make the United States the most attractive setting in which to study and perform research . . . , and ensure that the United States is the premier place in the world to innovate. . . ." (pp. 5-11). There are precious few national initiatives as broad in scope and technological reach as U.S. civil space activities. The broad array of enabling technologies required for successful space activities today and for future space missions encompasses robotics, advanced materials, advanced communications, advanced propulsion and power systems, biomedical sciences, and many more (Figure 2.7). Such areas of technology needed for success in space endeavors have a linkage to the technologies needed to address some of the nation's biggest challenges—including environmental management, climate change, economic development, and generation of clean energy. Civil space activities offer a unique

FIGURE 2.7 Programs like NASA's Scientific Balloon program help train the next generation of space scientists and engineers. Students can participate in balloon flight investigations to study a variety of topics in fields such as atmospheric science, solar-terrestrial physics, astronomy and astrophysics, and micrometeoritic science. At any given time, there are approximately 25 graduate students and 50 undergraduate students involved in the ballooning program. See NRC, *Building a Better NASA Workforce: Meeting the Workforce Needs for the National Vision for Space Exploration,* The National Academies Press, Washington, D.C., 2007, p. 39. SOURCE: Courtesy of NASA/University of Maryland and Jojo Boyle, University of Chicago.

opportunity to inspire and to educate current and future generations, yielding benefits beyond just space exploration.[17]

The NASA Authorization Act of 2008 states that "NASA, through its pursuit of challenging and relevant activities, can provide an important stimulus to the next generation to pursue careers in science, technology, engineering, and mathematics" (Figure 2.8). While specific to NASA, this statement applies to all aspects of the U.S. civil space program. Furthermore, a reputation for competence

[17] See National Research Council, *NASA's Elementary and Secondary Education Program: Review and Critique,* The National Academies Press, Washington, D.C., 2008, for specific recommendations about NASA education programs.

FIGURE 2.8 Schoolchildren enjoy Space Day 2005 at the National Air and Space Museum's Udvar-Hazy Center. Over a million people visit the Udvar-Hazy Center each year, and the National Air and Space Museum typically receives more than 5 million visitors each year (in 2007, it had more than 6 million visitors). SOURCE: Courtesy of Dane Penland, National Air and Space Museum, Smithsonian Institution.

in executing space missions that advance the frontier is likely to help attract talented foreign nationals to study and work in the United States, as well as to inspire our own students to enter technical fields.

Spirit of Optimism

Civil space activities also can exert an influence in building citizens' confidence in a brighter future. We live in a world with many immediate concerns—notably including a weakened world economy, regional conflicts and global terrorism, and threats of the consequences of climate change and limitations in energy sources. It is a time when people can be fearful that our tomorrows will be less promising than our past; that our children will have fewer opportunities than we enjoyed.

Surely, a vigorous civil space program will be a strong signal that our future as a nation is promising, that life can be better, that our prospects are boundless. Civil space assets, with their global perspective on the changing Earth, can provide knowledge to enable wise stewardship of our planet's bounty. We can become a true space-faring society with new opportunities for our economy. Civil space activities will add to knowledge of our place in the cosmos and thereby expand the cultural richness of our nation.

The United States, leading by example and in cooperation with others in the exploration and utilization of space, can be a strategic leader in the world, not to be feared or despised, but rather to be valued for its concerted attention to basic challenges facing people worldwide.

ENHANCE U.S. STRATEGIC LEADERSHIP

Strategic leadership for the United States means thinking about the future in a way that sees beyond immediate and particularly American needs and policies—such as ensuring access to resources or a temporary military advantage—and positioning the nation to help set an agenda for worldwide action. In considering both its own national interests and benefits to humankind, the United States should aim for more than immediate solutions to transitory problems and should find approaches that seek to shape the future.

Space is viewed by many countries of the world as a global commons, a resource not owned by any one nation but crucial to the future of all humankind. Indeed, human beings around the world view space not just as a place, but rather as symbolic of the future itself. For U.S. exertion of strategic leadership there is thus no venue more special than space. Through its efforts and achievements, the nation has earned its position of leadership in space. True strategic leadership will be achieved not by dominance, which in many cases is no longer possible, but by example and in cooperation with other nations. In addition to protecting those activities in space that are judged to be essential to U.S. national interest, and for which the United States must continue as an undisputed leader, there should also always be concern for the larger world and for how the United States is viewed as a benevolent nation with foresight and determination to make a better world for all humankind. *A goal of the U.S. civil space program is to enhance U.S. global strategic leadership through leadership in civil space activities.*

By achieving this goal, the U.S. civil space program will

- *Establish, exercise, and sustain global space leadership as an essential tool for U.S. global strategic leadership;*
- *Actively pursue and expand international partnerships; and*
- *Create a robust and safe space-operating regime and ensure that space becomes a more productive global commons for science, commerce, and other activities.*

Strategic Leadership

The goals just enumerated—Earth stewardship, scientific discovery, expanding human frontiers, technological, economic, and societal benefits, and inspiration—provide the foundation for a preeminent U.S. civil space program. If America chooses to achieve these goals, in support of national interests and in the interests of the world at large, we can also achieve a goal of particular importance—to enhance U.S. strategic leadership.

The strategic leadership that the United States needs to exert must be appropriate for the new era of globalization. The United States must strengthen ties to traditional allies and build increasingly effective working relationships with emerging powers. Civil space activities always have been, and will continue to be, excellent vehicles for promoting positive international relations and supporting the nation's foreign policy objectives. International collaboration in space provides a means to carry out nonthreatening activities that can coexist with sources of tension that may arise from other events. These collaborations and activities can play an important role in enhancing a positive U.S. image abroad.

International Collaboration

Exerting a global leadership role in space activities is the best means to ensure that space activities can serve the broader security and economic interests of the nation. The successful construction of the ISS has shown that a coalition of nations working together can accomplish large engineering feats in space. Some particularly pressing or ambitious space activities currently under discussion (e.g., measuring and monitoring global climate change or continuing with human exploration of the solar system) may only be possible through international collaboration. Such collaboration, however, requires an awareness that different nations may participate in different ways, and for different reasons. International cooperation in space, itself, is of at least two kinds—working on ambitious projects with other space-faring nations with significant capability and involving other nations wishing to get started in space to develop capability.

Space activities have potential for the nations of the developing world (maybe more so than for the developed nations that are the usual players). To these nations, space is a luxury item out of their reach. With few exceptions, they generally do not partake in space endeavors with the space-faring nations. Here the United States has an opportunity to bring development-relevant knowledge to the nations that most need it.

Global Commons

The United States has broad commercial and security interests in space, which must be protected. Important components of our civil and military infrastructure reside in space, and America can provide true security for those space assets by committing itself to use of the global commons[18] by all and by creating a mutual dependence in space that is in the best interests of all nations to protect. The United States need not rely solely on technological supremacy—which is always tenuous—but can instead build partnerships that will serve to maintain its strategic position as a global leader. Specifically, a system of customs and rules that organize the activities of many nations in space is necessary in order to prevent unintentional interference between space systems and help make space safer for all lawful activities (see Box 2.4).

An example of the consequences of the current lack of such coordination is the collision that destroyed an Iridium Corporation communications satellite in February 2009. The Iridium satellite and the dead Cosmos satellite were tracked, but the U.S. Air Force was not funded or responsible for calculating every possible conjunction. The data were available, but no one organization had the resources or accountability to perform the orbital projection. A global commons environment could have helped prevent the collision by having rules to de-orbit satellites past their functional lifetime, or by the sharing of orbital data among the satellite operators so that they could calculate possible conjunctions, or by having an international space surveillance governance mechanism by which to calculate all possible conjunctions (see Box 2.5).

It is incumbent upon the major space-faring nations to take the lead in establishing such customs and rules, as was done by the seafaring powers in centuries past and in global commercial aviation today, and in developing means to mitigate the threats to spacecraft safety that now exist. The United States has an opportunity to work cooperatively with other nations to protect its interests in space, but a strong and active civil space program is necessary to accomplish this goal.

[18] Global commons are assets that are not owned by anyone but are central to life and used for the good of all. The term is drawn from old English law where, for example, the village grazing commons for livestock was critical to sustaining village life and was commonly held property.

BOX 2.4
Stewardship of Space as a Global Commons

The UN Outer Space Treaty, to which the United States is a signatory, establishes all of the usable space outside Earth's atmosphere as a global commons open to all legal use by any state, entity, or individual. Although space seems extraordinarily vast, the most useful Earth orbits and spectral links are increasingly crowded and subject to natural and man-made debris and interference. Keeping space lanes safe and usable for lawful purposes, especially science and commerce, is a practical, civil-government function just as is managing the sea-lanes and international airspace.

Humankind's use of the space domain is relatively new. The number of state and private participants is growing, and there are many opportunities to set precedents. As more states get closer to landing on the Moon, the number of questions about interpretation of legal concepts such as property rights and peaceful uses is increasing. Will legal interpretations encourage free enterprise, for instance, for a commercial firm that wants to conduct mining on the Moon? Will untended or nonfunctional exploratory or scientific sites, like the Apollo landing sites or the Mars rovers, be legally protected from damage or disruption caused by later exploratory activities?

There are already formal proposed "rules of the road" for space being discussed at UN forums with State Department participation. (The EU presented a draft *Code of Conduct for Outer Space Activities,* December 19, 2008, for consideration by the UN Committee for the Peaceful Uses of Outer Space. The EU is now in the process of revising the document to make it acceptable to more countries.) It is in the U.S. national interest to actively conduct leading-edge human and robotic civil space activities that set positive legal and convention precedents; to exert technical and diplomatic leadership in the evolution of space stewardship systems, rules, and organizations; and to ensure that space continues to be a productive global commons for science, commerce, and other lawful activities.

The protection of solar system bodies from biological contamination carried by spacecraft from Earth and the protection of Earth from possible life forms returned from other solar system bodies also is an important responsibility for all space-faring nations. Planetary protection standards are developed by the Committee on Space Research of the International Council on Science in consultation with the UN. The United States has played a leadership role in planetary protection via technical standards developed by the National Research Council and implementation protocols developed by NASA.

BOX 2.5
Orbital Debris

Although the volume of space available for utilization is large, the most useful Earth orbital zones are increasingly crowded and subject to natural and man-made debris. In low Earth orbit, the International Space Station has maneuvered nine times over the past 10 years in order to avoid a potential collision. Communications satellites also face threats at geostationary Earth orbit altitudes (see Figure 2.5.1).

Space debris has many sources. Some objects are natural—small bits of extraterrestrial material drawn into orbit by Earth's gravity. Other objects are remnants of the space age. While most lower stages of large rockets fall back to Earth and burn up in the atmosphere, almost all final stages go into orbit. Furthermore, objects as small as paint chips can come off a rocket and pose a hazard to spacecraft. The U.S. Strategic Command tracks nearly 18,000 objects in Earth orbit, down to sizes of 10 cm across.

In recent years, many observers predicted that it was only a matter of time before an operating spacecraft was disabled by a collision. This prediction came true on February 11, 2009, when a satellite belonging to Iridium Satellite LLC collided with Cosmos 2251—a defunct Russian communications satellite. The collision resulted in a cloud of over 600 smaller pieces of debris.

Discussions of space debris mitigation are under way in the UN Committee on the Peaceful Uses of Outer Space and in other forums. These discussions provide an opportunity for the United States to lead the global community in preserving space—particularly the most useful Earth orbits—as a global commons. For more information, see National Research Council, *Orbital Debris: A Technical Assessment,* National Academy Press, Washington, D.C.,1995.

BALANCING SUPPORT FOR MULTIPLE GOALS

The civil space program is an integral part of the nation's R&D enterprise. To the extent that the United States chooses to increase its investments in R&D, components of the civil space program should be included. However, regardless of whether budgets are growing or constrained, there is always the need to balance among those components.

The committee's first four proposed goals for U.S. civil space efforts—Earth stewardship, advancing scientific knowledge, expansion of the frontiers of human spaceflight, and provision of technology, economic, and societal benefits—are

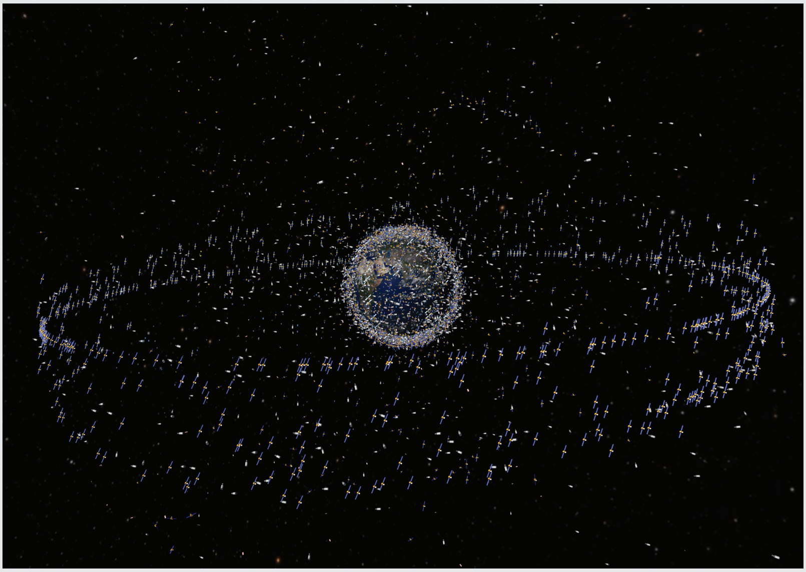


FIGURE 2.5.1 Artist's impression of the debris surrounding Earth. The number of objects in Earth orbit has increased steadily (by 200 per year on average) as more nations develop space programs. NOTE: Size of debris is greatly exaggerated as compared to the size of Earth. SOURCE: Courtesy of the European Space Agency.

programmatic goals. The committee identified three criteria for assessing balance in efforts to address the first four goals.

1. *Capacity to make steady progress*. Each major program area needs to be maintained at a level such that the highest-priority intermediate goals can be achieved at a reasonable pace and the next generation of technologies and technical expertise can be developed to sustain long-term progress.

2. *Stability*. Rapid downsizing or abrupt redirection of a space activity are disruptive. Reconstituting a lost science or engineering capability or recovering from a major change in program direction can take a long time. A major gap in

program activities can also add significant risk as new operations personnel learn without the benefit of experienced hands.

3. *Robustness*. Sufficient human resources and research infrastructure—including public and private institutions and world-class research facilities—need to be maintained to enable the nation to ramp up selected space activities within 1 or 2 years as national needs change or as major unexpected scientific or technical breakthroughs occur.

The committee's proposed fifth goal—inspiring current and future generations—links the program goals with people who support the civil space program. A program that advances the four program goals but does not stimulate educational opportunities or inspirational moments would fail to achieve the full potential of a strong U.S. civil space program.

The committee firmly believes that the U.S. civil space program can be a tool for addressing many of the challenges facing the nation. A space program that properly addresses the first four goals in a manner that also achieves the fifth will be a significant strategic asset for the nation. And by achieving these goals in support of national interests and in the interests of the world at large, we can also achieve a goal of particular importance—to enhance U.S. strategic leadership.

3

Foundational Elements

To contribute to realizing critical national objectives, including those listed in the previous chapter, the U.S. space program, both the civil and the national security components, must have a strong foundation and adequate resources. While the breadth of the civil space program has grown, there is also a sense that the program has been unfocused, with corresponding impacts on the organizations and institutions that support it. The United States can no longer pursue space activities on the assumption of its unchallengeable dominance—as evidenced by the view of other nations that the United States is not the only, or in some cases even the best, option for space partnerships. U.S. leadership in space activities and their capacity to serve urgent national needs must be based on preeminent technical capabilities; ingenuity, entrepreneurialism, and a willingness to take risks; and, recognition of mutual interdependencies. The time has come to reassess and, in some cases reinvent, the institutions, workforce, infrastructure, and technology base for U.S. space activities.

In the committee's view, four foundational elements are critical to a purposeful, effective, strategic U.S. space program, without which U.S. space efforts will lack robustness, realism, sustainability, and affordability.

1. *Coordinated national strategies*—implementing national space policy coherently across all civilian agencies in support of national needs and priorities and aligning attention to shared interests of civil and national security space activities;
2. *A competent technical workforce*—sufficient in size, talent, and experience to address difficult and pressing challenges;

3. *An effectively sized and structured infrastructure*—realizing synergy from the public and private sectors and from international partnerships; and

4. *A priority investment in technology and innovation*—strengthening and sustaining the U.S. capacity to meet national needs through transformational advances.

In the case of each of these elements, there are impediments and challenges that need to be overcome to ensure a strong foundation for the nation's civil space program, and the committee discusses some of these unresolved issues in the following sections.

ALIGNING THE NATION'S SPACE ACTIVITIES

The committee's conclusion is that the U.S. civil space program has made and will continue to make major contributions to the nation's welfare. Yet no processes are currently in place whereby all of the space activities of the federal government, whether civil or national security, can be properly aligned so that each element is assigned the resources required to achieve its mission and so that there is proper coordination across all of the government agencies involved. Since the beginning of the U.S. space program, there have been interdependencies and intersections between the national security and civil space communities. They share the same pool of trained talent, industrial base, technology advances, launch infrastructure, and ground and test equipment. Both must maintain awareness of the space environment (e.g., to anticipate and counter threats and risks due to radiation and debris); both can benefit from being able to share satellite-derived information (e.g., on weather, climate, and disaster situations) and the results of research conducted in universities and industrial laboratories; and both have needs for international coordination of space policy. Proper coherence among all of the elements of U.S. space activities—civil and national security—is thus important.

Given the broad mandates of civil and military space efforts and their influence on many aspects of U.S. society, economy, and national image, it is unrealistic and unworkable to expect that there should be a single space strategy. But a process, led by senior executive branch officials, that has as its purpose the proper alignment of the nation's space activities would help to ensure that each participating agency has the resources necessary to achieve its established goals; that avoidable duplication is reduced; and that the nation has the effective civil and military space programs that it requires.

Such a process for aligning the nation's space activities would involve establishing a long-term government commitment and realistic resources, and would define clear roles and responsibilities for government participants, and meaningful relationships with stakeholders outside the government; it would establish lines of authority and accountability, delineating priorities for national resources and leveraging important capabilities to achieve broad national goals. A successful process could provide stability to civil space projects and minimize changes in direction, priorities, and resources until the systemic effects of changes could be understood.

An effective process of alignment would lead to space activities that are cohesive, consistent, and persistent and would be shaped from a broad perspective on how civil space activities affect our economy, national security, and world influence. Civil space is often associated with NASA, but increasingly, other federal departments, including the Departments of Commerce and Transportation, have civil space programs. A growing private sector is active, as are important university and industrial research programs. The diffusion of civil space capabilities and responsibilities, however, is both beneficial (contributing to more parts of the economy and tapping the unique expertise of each agency) and problematic (confusing roles, missions, goals, and objectives). There is now both a special need and a special opportunity to align the strategies of the civil space agencies.

Because the nation's space activities—both civil and national security—are not isolated elements but instead interact with the broader aspects of U.S. commerce, transportation, education, and international relations, the process for aligning the nation's space activities should be well informed concerning the influence civil space already has throughout our society. And, even more important, it should reflect an understanding of the growing role of civil space in our lives.

The process should provide a framework for meaningful international relationships in civil space activities while realistically addressing national security priorities such as preventing transfer of militarily sensitive technologies to adversaries abroad. However, the current implementation of the International Traffic in Arms Regulations (ITAR) has significantly limited the ability of the United States to exert strategic leadership in civil space. The ITAR regulations have made it difficult for the United States to enter into and execute meaningful cooperative programs in either the human or the robotic exploration of space, and they are judged to have damaged the health of the U.S. aerospace industry.[1] The ITAR regulations have pushed other countries to develop indigenous space capabilities and have adversely affected U.S. market share, aerospace employment, and leadership. Since 1999, when communications satellites were moved to the Munitions List, the U.S. market share of satellite manufacturing revenues has dropped from above 60 percent to approximately 50 percent. The U.S. commercial communications satellite manufacturing share has dropped from 90 percent to 50 percent.[2] In addition, aside from the adverse civil aspects, several expert assessments have concluded that the current implementation of export control regulations is harming national security rather than helping it. For example, a recent NRC report,

[1] See Center for Strategic and International Studies, "Briefing of the Working Group on the Health of the U.S. Space Industrial Base and the Impact of Export Controls," February 2008, available at http://www.csis.org/media/csis/pubs/021908_csis_spaceindustryitar_final.pdf.

[2] Ibid., p. 50.

Beyond "Fortress America": National Security Controls on Science and Technology in a Globalized World, found that "current policies . . . weaken relations with allies, reduce the capability and strength of America's defense industrial base, and help to create foreign competitors that diminish U.S. market share in critical technologies."[3]

A coordinated, sustainable set of strategies should ensure that responsibilities are realistically matched to available resources. Such a match does not exist today. For example, NASA has a central role in civil space, yet by any reasonable measure it is inadequately funded to pursue its many responsibilities.[4] NASA now follows the U.S. space exploration policy established in 2004 by then President George W. Bush but must implement that policy within the budget constraints imposed by the Administration and Congress. The committee concurs with the primary conclusion of a 2006 NRC report,[5] which summarized the situation by saying: "NASA is being asked to accomplish too much with too little. The agency does not have the necessary resources to carry out the tasks of completing the International Space Station [ISS], returning humans to the Moon, maintaining vigorous space and Earth science and microgravity life and physical sciences programs, and sustaining capabilities in aeronautical research" (p. 2). Rather than requiring that a broad and ambitious program be fit into an arbitrarily constrained budget as has been the case in recent years, a sustainable strategy would first define the program that the nation is committed to undertake and then realistically define the resources that are required to accomplish that program.

NOAA faces a similar problem. The agency is charged with operating a space program to meet long-term operational meteorological needs as well as increasing requirements in the areas of climate monitoring and ecosystem management. Unfortunately, the agency's resources are inadequate to fulfill those roles. NASA transferred its responsibilities for monitoring climate change to NOAA a decade ago, with the expectation that the required instrumentation would be flown on the National Polar Orbiting Environmental Satellite System (NPOESS), jointly managed by NOAA and the DOD. NPOESS is now over budget and behind schedule. While some of the climate instruments that had been removed from NPOESS in recent years have been reinstated, a 2009 NRC report concluded that NPOESS

[3] National Research Council, *Beyond "Fortress America": National Security Controls on Science and Technology in a Globalized World,* The National Academies Press, Washington, D.C., 2009.

[4] An April 2009 report from the Congressional Budget Office, *The Budgetary Implications of NASA's Current Plans for Space Exploration,* concluded that NASA would need an annual average budget of $23.8 billion for the period 2010–2025 in order to meet its commitments, compared to a fiscal year 2009 budget of $18.8 billion, including $1 billion in 2009 American Recovery and Reinvestment Act funds. In testimony before the committee the (then) NASA Administrator, Michael Griffin, estimated that NASA would need approximately $20 billion to $21 billion annually to meet its commitments properly.

[5] National Research Council, *An Assessment of Balance in NASA's Science Programs,* The National Academies Press, Washington, D.C., 2006.

still lacks essential features of a well-designed climate-monitoring system.[6] Meanwhile, NASA's funding for Earth science has declined substantially, leaving the nation with aging and inadequate systems to provide an understanding of the present state and future of Earth's climate[7] despite the one-time infusion of $450 million in the 2009 American Recovery and Reinvestment Act package for Earth science. In testimony before the committee, former NOAA administrator, VADM Conrad Lautenbacher, indicated that NOAA was not funded adequately to meet its responsibilities in space, particularly over the long term.

The budgetary situations faced by NASA and NOAA are a consequence of a trend in recent administrations to view the space program as an isolated stovepipe, with little or no connection to the nation's most prominent problems. Civil space programs have largely been assigned budget levels that are incrementally based on previous years' budgets, with only tenuous connections to the evolution of the programs or their capabilities. An effective process would connect space policy to broader national needs, and then consider the necessary resources and implementation, improve efficiency by considering interdependencies and broad system effects, enhance productivity by providing focus and a longer-term view, and encourage a culture of collaboration among government agencies, the private sector (including both industry and academia), and international partners. This process would then provide a necessary foundation for continuing U.S. space leadership.

HIGHLY CAPABLE TECHNICAL WORKFORCE

The United States has been a space-faring nation for more than 50 years, and the experienced aerospace workforce that pioneered the exploration of space and engineered notable past accomplishments is quickly retiring. As of February 2009, more than 60 percent of NASA's full-time permanent employees were at least 45 years old, and nearly one quarter of employees were above 55. Assessments of the U.S. aerospace industry workforce give similar results for private sector employees.[8] The urgent need to replenish the aerospace science and engi-

[6] National Research Council, *Ensuring the Climate Record from the NPOESS and GOES-R Spacecraft: Elements of a Strategy to Recover Measurement Capabilities Lost in Program Restructuring,* The National Academies Press, Washington, D.C., 2009.

[7] According to the 2007 NRC report *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond:* "[T]he extraordinary U.S. foundation of global observations is at great risk. Between 2006 and the end of the decade, the number of operating missions will decrease dramatically, and the number of operating sensors and instruments on NASA spacecraft, most of which are well past their nominal lifetimes, will decrease by some 40 percent" (The National Academies Press, Washington, D.C., p. 3).

[8] While there are similar demographic issues in other federal agencies, data collected in "The Next Gen Space Workforce: Some Data and Questions in Advance of the NASA Strategic Management Council" by Garth Henning and Richard Leshner (NASA, Washington, D.C., April 2008) show that the aerospace sector is significantly different from other industries, such as information technology and telecommunications and finance.

neering talent pool spans both civil and military space and is particularly critical in the aerospace industry. Civilian and military agencies and private industry are all codependent on the same highly skilled aerospace workforce. A recent NRC report,[9] as well as others, also emphasized that certain skill areas, especially systems engineering and project management, are particularly understaffed and vulnerable to further shortages. To address those specific needs, a follow-on NRC report calls for more opportunities to provide hands-on training and experience with spaceflight development programs.[10]

A strong aerospace engineering workforce is only one component of the overall demand in our country for a strong science and engineering workforce. Aerospace engineering requirements compete nationally for much of the same technically trained talent needed across the broad research and engineering sectors of our country. Unfortunately, the United States is not meeting the consolidated needs for science and engineering expertise. *Rising Above the Gathering Storm* addressed this issue holistically and concluded that

> [T]he scientific and technical building blocks of our economic leadership are eroding at a time when many other nations are gathering strength. We strongly believe that a world-wide strengthening will benefit the world's economy—particularly in the creation of jobs in countries that are far less well-off than the United States—but we are worried about the future prosperity of the United States. Although many people assume that the United States will always be a world leader in science and technology, this may not continue to be the case inasmuch as great minds and ideas exist throughout the world. We fear the abruptness with which a lead in science and technology can be lost and the difficulty of recovering a lead once lost—if indeed it can be regained at all (p. 3).

The committee fully concurs with the findings and recommendations of that report, especially with respect to recruiting and training a skilled technical workforce and supporting long-term, potentially high-payoff basic research. Without a strong, diverse workforce, the civil space program will be unable to meet the opportunities and challenges it faces.

INFRASTRUCTURE

The myriad accomplishments of the U.S. space program depend on the underlying enabling infrastructure of facilities, organizations, and centers of expertise in government, industry, academia, and other private sector institutions.

[9] National Research Council, *Issues Affecting the Future of the U.S. Space Science and Engineering Workforce,* The National Academies Press, Washington, D.C., 2006.

[10] National Research Council, *Building a Better NASA Workforce: Meeting the Workforce Needs for the National Vision for Space Exploration,* The National Academies Press, Washington, D.C., 2007, pp. 38-43.

This infrastructure, much of it supported by NASA, was built on the National Advisory Committee for Aeronautics centers existing at the time of NASA's founding and was expanded during the ramp-up of the Apollo program. The NASA centers provide unique capabilities essential to the civil space program in the years ahead, including rocket test facilities, spacecraft assembly facilities and flight control centers, and launch facilities, as well as personnel with expertise that universities and industry could not necessarily supply. Some NASA centers have also served historically as incubators for innovation and have acted as repositories for the hard-won knowledge gained from years of experience, successes, and failures in space. Ironically, now that one of the nation's newest infrastructure assets, the ISS, has been completed, the funding to utilize it is uncertain, and near-term access depends on foreign launch systems.

DOD is responsible for the nation's launch complexes and ranges at Cape Canaveral Air Force Station and Vandenberg Air Force Base, which support military launches and which also provide collateral support to NASA and commercial launch operations. It also maintains the worldwide space surveillance network used by all U.S. agencies, as well as commercial and foreign entities, and a satellite command and control network that provides support to civil operations. Like GPS, this military-managed infrastructure is essential to the U.S. civil space program. The DOD also supports cooperative space development testing with its own space facilities in cooperation with NASA and commercial programs.

Essential infrastructure is also provided by NOAA, which has an array of tracking stations and data and information systems to conduct its meteorological and environmental satellite observing programs. U.S. universities and both federal and nongovernment laboratories house many of the organizations and facilities where U.S. space science and engineering research is conducted. And of course, it is in university classrooms, laboratories, and many specialized facilities that the technical workforce is educated; some universities have also built and operated satellites. Today, most development and manufacturing facilities and staffs supporting U.S. space activities reside in private industry. U.S. civil space activities thus depend on an infrastructure that spans government, industry, and academia.

Now the health of this institutional infrastructure is in question. NASA still maintains 10 large centers, as legacies of its much larger Apollo program more than 40 years ago. Responding to funding limitations and associated political pressures, NASA has elected to focus its support on its own centers but has strained to maintain all of these facilities, their staffs, and their programs. The strain has forced reductions in funds for research within NASA and in the supporting academic and industrial sectors as well. As a result, the broad national capabilities in universities and in industry have atrophied and are underutilized—and in some instances imperiled—with serious consequences for U.S. capabilities for future innovation.

In the case of universities, where research and education are pursued synergistically, the proper training of the aerospace workforce is in jeopardy. In the academic sector, the fact that NASA has terminated some university-based efforts has adversely affected not only the conduct of research but also the pipeline of undergraduate and graduate students upon which the civil space community depends—an unintended, but nonetheless alarming, consequence.

When the NASA centers and other government installations are leveraged along with the talent in universities and the capabilities and facilities of the aerospace industry, a powerful capacity exists to accomplish extraordinary civil space missions. A healthy U.S. civil space program should be able to optimize the participation and responsibilities of all three involved sectors—government, industry, and academia. Such an optimized institutional partnership would

- Develop and nurture a culture of cooperation achieved through sharing of facilities and intellectual capacity;
- Ensure that facilities—at NASA, NOAA, and elsewhere—are sized, maintained, and distributed properly so as to be vital components of a larger civil space enterprise without their maintenance becoming an impediment to a balanced division of resources within and outside the agencies;
- Provide necessary support for facilities, human capital, technology transition, innovation, and entrepreneurial activities; and
- Regularly assess mission performance, technical expertise, and the strengths of interactions across all three sectors.

TECHNOLOGY AND INNOVATION

Future U.S. leadership in space requires a foundation of sustained technology advances that can enable the development of more capable, reliable, and lower-cost spacecraft and launch vehicles to achieve space program goals. A strong advanced technology development foundation is needed also to enhance technology readiness of new missions, mitigate their technological risks, improve the quality of cost estimates, and thereby contribute to better overall mission cost management.

Space research and development efforts can take advantage of advances from other fields—and can contribute back to those fields. For example, civil space programs can benefit from and contribute to the state of the art in advanced materials, computational design and modeling, batteries and other energy-storage devices, fuel-cell and compact nuclear power systems, fault-tolerant electronics, optics, and robotics. This scientific synergy extends the ability to accomplish more capable and dramatic missions in space, as well as to contribute to broader national interests driving innovation in other areas of terrestrial application. The unique challenges of the space environment make demands on technology in ways that often accelerate the development pace and advance the understanding of the foundations of technologies.

The responsibility to provide for this advanced technology base for civil space activities rests with NASA, in partnership with universities, other government agencies, and industry. The "customers" for the products of technology are NASA, NOAA, industry, and military space programs in which multiple-use technology is applicable. Because of budget pressures and institutional priorities, however, NASA has largely abandoned its role in supporting the broad portfolio of civil space applications, and the space technology base has thus been allowed to erode and is now deficient. The former NASA advanced technology development program no longer exists. Most of what remained was moved to the Constellation Program and has become oriented specifically to risk reduction supporting the ongoing internal development program.[11]

To fulfill NASA's broader mandate, an independent advanced technology development effort is required, much like that accomplished by DARPA in the DOD, focused not so much on technology that today's program managers require but on what future program managers would wish they could have if they knew they needed it, or would want if they knew they could have it. This effort should engage the best science and engineering talent in the country wherever it resides—in universities, industry, NASA centers, or other government laboratories—independent of pressures to sustain competency at the NASA centers. A DARPA-like organization established within NASA should report to NASA's Administrator, be independent of ongoing NASA development programs, and focus on supporting the broad civil space portfolio through the competitive funding of world-class technology and innovation projects at universities, federally funded research and development centers, government research laboratories, and NASA centers.

A solid technology base is essential to the U.S. civil space program. Yet financial support for this technology base has eroded over the years. The United States is now living on the innovation funded in the past and has an obligation to replenish this foundational element. Furthermore, the synergy between research and education will yield even greater benefits if funding supports an extramural program at U.S. universities. University research ensures a diverse approach, connection to a broad research community, and encouragement of a pipeline of technically talented men and women for the U.S. workforce.

SUMMARY COMMENTS

Four foundational elements—an integrated strategy, a highly capable technical workforce, an effectively sized infrastructure, and a priority investment in

[11] National Research Council, *A Constrained Space Exploration Technology Program: A Review of NASA's Exploration Technology Development Program,* The National Academies Press, Washington, D.C., 2008.

technology and innovation—are necessary for a robust and productive U.S. civil space program. In the annual discussions of individual programs and agency budgets, these elements are not often mentioned, and if they are it is usually in some small aside. However, the U.S. civil space program would have more effect, a broader reach, and a greater connection to the American people if senior officials paid more attention to these elements.

4

Recommendations

The U.S. civil space program has become integral to achieving goals significant to the nation. Civil space activities offer the promise of helping to address challenging national imperatives, such as ensuring national security, protecting the environment, providing clean and affordable energy, meeting 21st-century needs for education, sustaining global economic competitiveness, and promoting beneficial international relations. Because civil space activities benefit citizens' lives and the national interest in so many tangible and intangible ways, the U.S. civil space program should be structured and provided with resources commensurate with its multiple responsibilities. The committee concluded that given their demonstrated utility and future promise, elements of the civil program should be aligned to fully serve the larger national interest, and decisions about civil space priorities, strategies, and programs, and the resources to achieve them, should always be made with a conscious view toward their linkages to broad national interests.

ADDRESSING NATIONAL IMPERATIVES

Recommendation 1. *Emphasis should be placed on aligning space program capabilities with current high-priority national imperatives, including those where space is not traditionally considered. The U.S. civil space program has long demonstrated a capacity to effectively serve U.S. national interests.*

Recommendation 1 provides a broad policy basis on which the committee's subsequent specific recommendations rest. The recommendations that follow address a set of actions, all of which are necessary to strengthen the U.S. civil space program and reinforce or enhance the contributions of civil space activities to broader national objectives.

CLIMATE AND ENVIRONMENTAL MONITORING

Recommendation 2. *NASA and NOAA should lead the formation of an international satellite-observing architecture capable of monitoring global climate change and its consequences and support the research needed to interpret and understand the data in time for meaningful policy decisions*.

The committee recognizes the important role in climate change studies that was assigned to the NPOESS and that is now in question, and the committee also concurs with the recommendations in the NRC report *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond* calling for a compelling program of Earth-monitoring space systems. Therefore, the committee recommends that

a. NASA and NOAA, working in concert with the private sector, academe, the public, and international partners, should reverse the deterioration of the U.S. space infrastructure for observing and understanding the climate of Earth and the human influence on it.

b. NASA and NOAA, in consultation with the scientific community, should develop and implement a plan for achieving and sustaining global Earth observations. This plan should recognize the complexity of differing agency roles, responsibilities, and capabilities, as well as the lessons from past government efforts.

c. NASA and NOAA should work with the international community to develop an integrated database for sensor information collected by all Earth-monitoring satellites so that researchers and decision makers have uninhibited access to this important information. This is an opportunity for the United States to demonstrate technical leadership in an area of international interest.

d. NASA and NOAA should aggressively pursue technology development that supports high-priority Earth observation missions and foster innovative approaches to meeting future space system needs.

e. NASA and NOAA should plan for transitions to continue demonstrably useful research observations on a sustained, or operational, basis.

SCIENTIFIC INQUIRY

Scientific inquiry and advancement of knowledge are fundamental to a nation's health: the results inform and excite the public, stimulate technology development, create an interest in learning, and generally improve the capacity of the nation to compete and to lead. A nation that asks questions about the universe and wants to learn is a richer nation.

Recommendation 3. *NASA, in cooperation with other agencies and international partners, should continue to lead a program of scientific exploration and discovery* that

a. Seizes opportunities to advance understanding of Earth, the objects of the solar system, including the Sun, and the vast universe beyond;

b. Includes searches for evidence of life beyond Earth;

c. Contributes to understanding how the universe works, who we are, where we came from, and what is the destiny of our star—the Sun—our solar system, and the universe, and of the physical laws that govern them; and

d. Is guided by peer review, advisory committees, and the strategies and priorities articulated by the science communities in their strategic planning reports, such as the NRC's decadal surveys.[1]

ADVANCED SPACE TECHNOLOGY

Civil and national security space activities share the same foundations of workforce, infrastructure, and technology. It is vital that the United States become prepared strategically to maintain a robust foundation in these areas to support future national needs.

Recommendation 4. *NASA should revitalize its advanced technology development program by establishing a DARPA-like organization within NASA as a priority mission area to support preeminent civil, national security (if dual-use), and commercial space programs.*

The resulting program should

- Be organizationally independent of major development programs;
- Serve all civil space customers, including the commercial sector;
- Conduct an extensive assessment of the current state and potential of civil space technology; and
- Conduct cutting-edge fundamental research in support of the nation's space technology base.

This effort should engage the best science and engineering talent in the

[1] The NRC decadal surveys have been widely used by the scientific community and by program decision makers because they (a) present explicit, consensus priorities for the most important, potentially revolutionary science that should be undertaken within the span of a decade; (b) develop priorities for future investments in research facilities, space missions, and/or supporting programs; (c) rank competing opportunities and ideas and clearly indicate which ones are of higher or lower priority in terms of the timing, risk, and cost of their implementation; and (d) make the difficult adverse decisions about other meritorious ideas that cannot be accommodated within realistically available resources.

country wherever it resides in universities, industry, NASA centers, or other government laboratories, independent of pressures to sustain competency at the NASA centers. A DARPA-like organization should be established within NASA, reporting to NASA's Administrator and independent of ongoing NASA development programs. This organization should be focused on supporting the broad civil space portfolio through the competitive funding of world-class technology and innovation projects at universities, federally funded research and development centers, government research laboratories, and NASA centers. The responsibilities of the organization should be similar to those of NASA's aeronautics research in the sense that the research activities should be supportive of the needs of the private sector as well as the government.

INTERNATIONAL COOPERATION

Recommendation 5. *The government, under White House leadership, should pursue international cooperation in space proactively as a means to advance U.S. strategic leadership and meet national and mutual international goals* by

a. Expanding international partnerships in studies of global change;

b. Leading an effort in which the United States and other major space-faring nations cooperate to develop rules for a robust space operating regime that ensures that space becomes a more productive global commons for science, commerce, and other activities;

c. Rationalizing export controls so as to ensure that ongoing prevention of inappropriate transfer of sensitive technologies to adversaries while eliminating barriers to international cooperation and commerce that do not contribute effectively to national security;[2]

d. Expanding international partnerships in the use of the International Space Station (ISS);

e. Continuing international cooperation in scientific research and human space exploration;

f. Engaging the nations of the developing world in educating and training their citizens to take advantage of space technology for sustainable development; and

g. Supporting the interchange of international scholars and students.

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[2] The committee does not recommend abandoning export controls but concurs with the recommendations of the NRC report *Beyond "Fortress America": National Security Controls on Science and Technology in a Globalized World* (The National Academies Press, Washington, D.C., 2009), which call for a restructuring of "the export control process within the federal government so that the balancing of interests can be achieved more efficiently and harm can be prevented to the nation's security and technology base, in addition to promoting U.S. economic competitiveness" (p. 6).

HUMAN SPACEFLIGHT

Because of its capacity to advance the tangible and intangible goals associated internationally with human spaceflight, the U.S. civil space program can serve geopolitical objectives in addition to advancing specific space exploration goals.

Recommendation 6. *NASA should be on the leading edge of actively pursuing human spaceflight, to extend the human experience into new frontiers, challenge technology, bring global prestige, and excite the public's imagination.*

These goals should be accomplished by

a. Setting challenging objectives that advance the frontier, scientific and technological understanding, and the state of the art;

b. Establishing clear goals for each step in a sequence of human spaceflight missions beyond low Earth orbit that will develop techniques and hardware that can be used in a next step further outward;

c. Focusing use of the ISS on advancing capabilities for human space exploration (e.g., by demonstrating large-scale reuse of water, developing largely autonomous crew operations, and rigorously investigating key space medical issues); and

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

Human spaceflight activities should be prioritized by their potential for and likelihood of producing a transformative cultural, scientific, commercial, or technical outcome. Such results could include achievement of a fundamentally new understanding or perspective, a more comprehensive approach, an essential new enabling capability, or the opportunity to visit and observe some unique new location. However, policy makers should recognize that these activities can require many years and a long-term commitment to come to fruition.

ORGANIZING TO MEET NATIONAL NEEDS

As the committee has noted earlier, national space policy too often has been implemented in a stovepipe fashion that obscures the connection between space activities and other pressing needs of the nation. Consequently, senior policy makers with broad portfolios have not been able to take the time to consider the space program in the broader national context. Rather, policies have been translated into programs by setting budget levels and then expecting agencies to manage to those budgets. The committee believes that the process of aligning roles and responsibilities for space activities, making resource commitments, and coordinating across departments and agencies needs to be carried out at a sufficiently high level that decisions are made from the perspective of the larger national issues regarding which space activities play roles. How this process is accomplished might change from administration to administration, but the need for an approach that will elevate attention to the proper level remains essential.

Recommendation 7. *The President of the United States should task senior executive-branch officials to align agency and department strategies; identify gaps or shortfalls in policy coverage, policy implementation, and resource allocation; and identify new opportunities for space-based endeavors that will help to address the goals of both the U.S. civil and national security space programs.*

The effort should include the Assistant to the President for National Security Affairs and the Assistant to the President for Science and Technology, and should consider the following elements:

a. Coordinating budgetary guidance across federal departments and agencies involved in space activities;

b. Coordinating responsibility and accountability for resource allocations for common services and/or infrastructure;

c. Coordinating responsibility and accountability for stimulating, nurturing, and sustaining a robust space industrial base, including the commercial space industry;

d. Coordinating responsibility and accountability for initiatives to recruit and develop a competent aerospace workforce of sufficient size and talent, anticipating future needs;

e. Identifying, developing, and coordinating initiatives to address long-range technological needs for future programs;

f. Identifying, developing, and coordinating initiatives to establish and strengthen international space relationships;

g. Harmonizing the roles and responsibilities of federal agencies to eliminate gaps and unnecessary duplication in the nation's space portfolio; and

h. Regularly reviewing coordinated national space strategies and their success in implementing overall national space policy.

As indicated in Chapter 3, the committee agrees with the conclusions of prior studies that the civil space program is not funded at the level needed to successfully accomplish its varying missions. Coordinated budgetary guidance will enable the Administration to view the nation's portfolio of space programs as a whole and make better-informed decisions about the programs' goals and requirements.

Aligning the strategies of the various civil and national security space agencies will address many current issues arising from or exacerbated by the current uncoordinated, overlapping, and unilateral strategies. A process of alignment offers the important advantage of leveraging the resources, talents, and capacity for innovation from various agencies to address such shared challenges as the diminished space industrial base, the dwindling technical workforce, and reduced funding levels.

A recent congressionally mandated report, *Leadership, Management and Organization of National Security Space,*[3] raised those points and recommended an integrated national space strategy. The committee agrees on the need for a process to define a national space strategy, and believes that the Office of Science and Technology Policy and the National Security Council must play a leading role in the process.

All of the agencies involved in the national security and civil space communities share the same pool of trained talent, industrial base, technology advances, launch infrastructure, and ground and test equipment. They all benefit from research conducted in universities and industrial laboratories, and they all have needs for international coordination of space policy. Coordinating the responsibility and accountability for these national resources will help to ensure their efficient use and maintenance, as well as provide a platform for planning future upgrades in capability.

There is an urgent need to replenish the aerospace science and engineering talent in the government and industry workforce and to restore the base of expertise in certain critical skill areas. Only with a strong, diverse workforce will the civil space program be able to meet the opportunities and challenges now facing the nation.

U.S. space activities—both civil and national security—are not isolated elements of the national enterprise. They interact with the broader aspects of our nation's commerce, transportation, education, and international relations. Civil space activities always have been, and will continue to be, excellent vehicles for educating future scientists and engineers, promoting positive international relations, and supporting the nation's foreign policy objectives. In short, they exist to serve national priorities and consequently should be understood and aligned in that light, and their progress toward effectively implementing national space policy and serving the national interest assessed accordingly.

RECOMMENDATIONS IN CONTEXT

As noted at the outset of this chapter, Recommendation 1 calls for a broad policy foundation that will maximize the potential for civil space activities to contribute to addressing major national needs and objectives. Recommendations 2 through 6 outline specific, immediate actions to enhance those contributions via climate change and environmental monitoring programs, scientific research,

[3] National Security Space Assessment Panel, *Leadership, Management, and Organization for National Security Space*, Institute for Defense Analyses, Alexandria, Va., September 2008.

advanced space technology development for government and industry, international cooperation, and human spaceflight programs. Recognizing that the U.S. civil space program cuts across many federal agencies and shares important aspects with the national security space program, Recommendation 7 urges that the federal government begin to align those space activities so that they will serve the national interest effectively.

Appendixes

A

Committee Member and Staff Biographies

LESTER L. LYLES, *Chair,* is a consultant with the Lyles Group. He retired from the U.S. Air Force (USAF) in 2003 as commander of the Air Force Material Command at Wright-Patterson Air Force Base (AFB) in Ohio. General Lyles entered the USAF in 1968 as a distinguished graduate of the Air Force ROTC program. He served in various positions, including program element monitor of the Short-Range Attack Missile at USAF Headquarters (USAF/HQ), special assistant and aide-de-camp to the commander of Air Force Systems Command (AFSC), chief of the Avionics Division in the F-16 Systems Program Office, director of Tactical Aircraft Systems at AFSC headquarters, and as director of the Medium-Launch Vehicles Program and Space-Launch Systems offices. General Lyles became AFSC headquarters' assistant deputy chief of staff for requirements in 1989, and deputy chief of staff for requirements in 1990. In 1992, he became vice commander of Ogden Air Logistics Center at Hill AFB in Utah. He served as commander of the center until 1994, when he was assigned to command the Space and Missile Systems Center at Los Angeles AFB in California. In 1996, General Lyles became the director of the Ballistic Missile Defense Organization. In May 1999, he was assigned as vice chief of staff at USAF/HQ. He is a member of the National Research Council (NRC) Air Force Studies Board and served on the NASA Advisory Council. His numerous awards include the Defense Distinguished Service Medal, the Astronautics Engineer of the Year from the National Space Club, the National Black Engineer of the Year Award, Honorary Doctor of Laws from New Mexico State University, and NASA's Distinguished Public Service Medal for serving on the President's Commission on Implementing the U.S. Space Exploration Policy.

RAYMOND S. COLLADAY, *Vice Chair,* is a retired corporate officer of Lockheed Martin Corporation and a former president of Lockheed Martin Astronautics Company. Before entering the private sector, he served as director of the Defense Advanced Research Projects Agency and as a NASA associate administrator for the Office of Aeronautics and Space Technology. At NASA he had senior executive responsibility for the agency's aeronautics and space research and technology development including operations oversight of Ames, Langley, Dryden, and Glenn research centers. He has been a member of the Air Force Scientific Advisory Board and various Defense Science Board summer studies. Dr. Colladay owns an aerospace consulting company, RC Space Enterprises, Inc. He also teaches leadership and ethics for the Colorado School of Mines and serves on a number of steering committees, boards, and commissions. He is chair of the NRC Aeronautics and Space Engineering Board and has served on six NRC study committees, four of which he chaired.

LENNARD A. FISK, *Vice Chair,* is the Thomas M. Donahue Distinguished University Professor of Space Science in the Department of Atmospheric, Oceanic, and Space Sciences at the University of Michigan. He is an active researcher in both theoretical and experimental studies of the solar atmosphere and its expansion into space to form the heliosphere. He was the associate administrator for space science and applications and chief scientist at NASA from 1987 to 1993. From 1977 to 1987, he served as professor of physics and vice president for research and financial affairs at the University of New Hampshire. He is a member of the National Academy of Sciences (NAS) and the board of directors of the Orbital Sciences Corporation and a co-founder of the Michigan Aerospace Corporation. He is a former chair of the NRC Space Studies Board, and his prior NRC service also includes the Committee on Scientific Communication and National Security, the Committee on Fusion Science Assessment, the Committee on International Space Programs, the Air Force Physics Research Committee, and the Committee on Solar and Space Physics.

JAY APT is Distinguished Service Professor in Engineering and Public Policy at Carnegie Mellon University (CMU). He also serves as executive director of the CMU Electricity Industry Center, and he is associate research professor in the Tepper School of Business. He was director of the Carnegie Museum of Natural History from 1997 to 2000. Dr. Apt began his career in 1976 as a postdoctoral fellow in laser spectroscopy at the Massachusetts Institute of Technology (MIT). He served as the assistant director of Harvard University's Division of Applied Sciences from 1978 to 1980. He then joined the Earth and Space Sciences Division of the Jet Propulsion Laboratory (JPL). In 1981 he became science manager of JPL's Table Mountain Observatory. From 1982 to 1985, he was a flight controller responsible for shuttle payload operations at NASA's Johnson Space Center. Dr. Apt is a former astronaut who has flown in space four times and performed two space walks. He was a member of the NRC Panel on Earth Science Applications and Societal Needs of the Survey Steering Committee for Earth Science and Applications from Space: A Community Assessment and Strategy for the Future.

JAMES B. ARMOR, JR., retired as major general from the USAF in 2008. His last position was as director of the National Security Space Office (NSSO) in the National Reconnaissance Office (NRO). There he led efforts to align and architect all military and intelligence space activities, and to coordinate with those of civil space. He jointly coordinated with the Department of Commerce to understand the adverse impact of U.S. import and export regulations on the space industrial base. Prior to the NSSO position, he served as director of Signals Intelligence Acquisition and Operations at NRO, as director of the NAVSTAR Global Positioning System, and he was a NASA astronaut who participated in a number of military missions carried by the space shuttle. Major General Armor is an elected associate fellow of the American Institute of Aeronautics and Astronautics (AIAA). He is currently founder and CEO of the Armor Group, LLC, a space consulting firm.

WANDA M. AUSTIN is the president and CEO of the Aerospace Corporation. She previously served as a senior vice president of the company's National Systems Group, which supports the national security space and intelligence community in the acquisition, launch, and orbital operation of advanced technology space systems and their ground data stations. She was elected a corporate officer of the company in 2001 and served as the senior vice president of the Engineering and Technology Group. She is internationally recognized for her work in satellite and payload system acquisition, systems engineering, and system simulation. Her numerous awards include the National Intelligence Medallion, the Air Force Meritorious Civilian Service Medal for her service on the Air Force Scientific Advisory Board, and the 2009 Black Engineer of the Year award. She is a member of the National Academy of Engineering (NAE), a fellow of the AIAA, and a member of the International Academy of Astronautics (IAA). She has served on the NASA Advisory Council, the NASA Aerospace Safety Advisory Panel (ASAP), and NRC Government-University-Industry Research Roundtable.

DAVID BALTIMORE is the Robert Andrews Millikan Professor of Biology at the California Institute of Technology (Caltech). His research interests focus on virology, immunology, cancer, and AIDS. He was awarded a 1975 Nobel Prize for Physiology or Medicine. Dr. Baltimore served as president of Caltech from 1997 to 2006 and as president of Rockefeller University from 1990 to 1991. He was president of the American Association for the Advancement of Science (AAAS) in 2007. Dr. Baltimore is a member of numerous organizations and boards, including Amgen, Inc., board of directors; BB Biotech AG board of directors; Jackson Laboratory board of directors; and, previously, chair of the National Institutes of

Health AIDS Vaccine Research Committee. He is a member of both the NAS and the Institute of Medicine (IOM), and he has served as co-chair of the NAS/IOM Committee on a National Strategy for AIDS, the NRC Committee on Science, Security, and Prosperity in a Changing World, and the Committee on Scientific Communication and National Security.

ROBERT BEDNAREK is CEO of SES AMERICOM/NEW SKIES and a member of the executive committee of SES. Mr. Bednarek was formerly with SES GLOBAL where he served as executive vice president for corporate development as well as a member of the executive committee. Before joining SES in 2002, Mr. Bednarek held the position of executive vice president and chief technology officer at satellite operator PanAmSat. Prior to joining PanAmSat, Mr. Bednarek was the co-founder and partner of a Washington, D.C.-based technology-consulting firm, Rubin, Bednarek, and Associates, specializing in communication systems engineering and technical regulatory matters pending before the Federal Communications Commission. He previously served as deputy chief scientist for the U.S. Corporation for Public Broadcasting. Mr. Bednarek is currently a board member of the nonprofit Space Foundation.

JOSEPH A. BURNS is the Irving Porter Church Professor of Engineering, Theoretical and Applied Mechanics and a professor of astronomy at Cornell University. His research interests center on using the principles of mechanics and classical physics to understand various aspects of the current structure of the solar system. He is particularly interested in the structure and dynamics of planetary rings. Dr. Burns is a member of the Cassini Imaging Team. He has curated exhibits of those images simultaneously being shown at the American Museum of Natural History (NYC) and the National Air and Space Museum. Dr. Burns is a fellow of the American Geophysical Union, the AAAS, and the Royal Astronomical Society. He is an elected member of the Russian Academy of Sciences and the IAA. He has been a vice president of the American Astronomical Society and has chaired their divisions for Planetary Sciences and of Dynamical Astronomy. His NRC experience includes membership on the Committee on Planetary and Lunar Exploration (chair), the Space Studies Board, the Committee on a New Science Strategy for Solar System Exploration (solar system exploration decadal survey), and the Panel on Ultraviolet, Optical, and Infrared Astronomy from Space of the Astronomy and Astrophysics Survey Committee.

PIERRE CHAO is a senior associate with the Center for Strategic and International Studies (CSIS), and managing partner of Renaissance Strategic Advisors. While at CSIS from 2003 to 2007 as a senior fellow, his work focused on policy issues related to the defense industrial base, including defense industrial policy, acquisition reform, transatlantic relations, export controls, and technology/innovation policy. Before joining CSIS in 2003, Mr. Chao was a managing director and senior aerospace/defense analyst at Credit Suisse First Boston (CSFB), where he was responsible for following the U.S. and global aerospace/defense industry. Prior to joining CSFB, Mr. Chao was the senior aerospace/defense analyst at Morgan Stanley Dean Witter. He served as the senior aerospace/defense industry analyst at Smith Barney and as a director at JSA International, a Boston/Paris-based management-consulting firm that focused on the aerospace/defense industry. Mr. Chao was also a co-founder of JSA Research, an equity research boutique specializing in the aerospace/defense industry. He is a member of the NRC Aeronautics and Space Engineering Board, and he has served as a member of the Committee on Critical Technology Accessibility.

KENNETH S. FLAMM is the Dean Rusk Chair in International Affairs at the Lyndon B. Johnson School of Public Affairs at the University of Texas at Austin. Dr. Flamm's expertise is in international trade and high-technology industry. From 1993 to 1995, he served as principal deputy assistant secretary of defense for economic security and special assistant to the deputy secretary of defense for dual-use technology policy. Prior to his service at the Department of Defense, he spent 11 years as a senior fellow in the Foreign Policy Studies Program at the Brookings Institution. Dr. Flamm has been a professor of economics at the Instituto Tecnologico A. de Mexico in Mexico City, the University of Massachusetts, and George Washington University. He has also been an adviser to the director general of income policy in the Mexican Ministry of Finance and a consultant to the Organization for Economic Cooperation and Development, the World Bank, the Latin American Economic System, the Department of Justice, the U.S Agency for International Development, and the Office of Technology Assessment. He has extensive NRC experience, including current membership on the Committee on Capitalizing on Science, Technology, and Innovation and the Committee on Comparative Innovation Policy, and former service on the Board on Science, Technology, and Public Policy.

JOAN JOHNSON-FREESE is chair of the Department of National Security Decision Making at the U.S. Naval War College (NWC). Prior to that, she held positions as chair of the Transnational Studies Department at the Asia Pacific Center for Security Studies in Honolulu, Hawaii, as a faculty member at the Air War College in Montgomery, Alabama, and as director of the Center for Space Policy and Law at the University of Central Florida. Dr. Johnson-Freese has focused her research and writing on security studies generally, and space programs and policies specifically, including issues relating to technology transfer and export, missile defense, transparency, space and regional development, transformation, and globalization. She is on the editorial board of China Security and a member of the IAA and the International Institute for Strategic Studies. She has testified before Congress concerning U.S.-Sino security issues concerning space. Dr.

Johnson-Freese's latest book is *Heavenly Ambitions: America's Quest to Dominate Space*.

PAUL D. NIELSEN is the CEO and director of Carnegie Mellon University's Software Engineering Institute. Dr. Nielsen served in the USAF and retired as a major general after 32 years of distinguished service. He served as commander of the Air Force Research Laboratory at Wright-Patterson AFB and as the Air Force technology executive officer and as vice commander of the Aeronautical Systems Center. He held assignments at the Department of Energy's Lawrence Livermore National Laboratory, the Office of the Secretary of Defense, the Cheyenne Mountain Operations Center, and the North American Aerospace Defense Command. In 2004, Dr. Nielsen became a fellow of the AIAA. He served as the AIAA president from 2007 to 2008 and was a member of the AIAA board of directors from 2006 until 2009. In 2006, he was elected as a fellow of the Institute of Electrical and Electronic Engineers. Dr. Nielsen serves on the Air Force Scientific Advisory Board and is a member of the board of directors for the Hertz Foundation.

MICHAEL S. TURNER is the Rauner Distinguished Service Professor in the Kavli Institute for Cosmological Physics, the Department of Astronomy and Astrophysics, and the Department of Physics at the University of Chicago. He served as assistant director for the Mathematical and Physical Science Directorate at the National Science Foundation (NSF) from 2003 to 2006 and as chief scientist at Argonne National Laboratory (ANL) from 2006 to 2008. Dr. Turner helped to bring together astronomers and particle physicists to create the interdisciplinary field of particle astrophysics and cosmology. He has made important contributions to cosmology in the areas of particle dark matter and its role in the formation of structure in the universe, inflationary cosmology, and understanding how dark energy (a term he coined) is causing the expansion of the universe to speed up. He is a member of NRC Board on Physics and Astronomy and is chair of the Physics Section of the NAS. He also serves on the Council of the NAS. He has served on numerous other NRC committees, including the Committee on NASA Astrophysics Performance Assessment, the Astronomy and Astrophysics Survey Committee, and the Committee on the Physics of the Universe (chair). Dr. Turner is a fellow of the American Physical Society, the American Academy of Arts and Sciences, and the AAAS.

THOMAS H. VONDER HAAR is the former director of the Cooperative Institute for Research in the Atmosphere (CIRA) and University Distinguished Professor of Atmospheric Science at Colorado State University. His studies on the interaction of clouds, water vapor, and radiation formed a basis for national and international plans that led to the Global Energy and Water Experiment and other programs related to global change. In 1980, Dr. Vonder Haar took the lead in forming CIRA, a center for international cooperation in research and training, covering virtually all physical, economic, and societal aspects of weather and climate. Dr. Vonder Haar is also director of the Center for Geosciences, a Department of Defense–sponsored research center that focuses on the study of weather patterns and how they affect military operations, including investigations of fog, cloud layering, cloud drift winds, and dynamics of cloud persistence as detected from satellites. He was honored as a Fellow and with the Charney Award by the American Meteorological Society and was elected to NAE in 2003. In 2005 to 2007 he served as vice chair of the Weather Panel for the NRC study that authored the report *Earth Science and Applications from Space—National Imperatives for the Next Decade and Beyond* (2007).

Staff

JOSEPH K. ALEXANDER, *Co-Study Director,* served previously as director of the Space Studies Board (SSB; 1998-2005); deputy assistant administrator for science in the Environmental Protection Agency's Office of Research and Development (1994-1998); associate director of space sciences at NASA Goddard Space Flight Center (1993-1994); and assistant associate administrator for space sciences and applications in the NASA Office of Space Science and Applications (1987-1993). Other positions have included deputy NASA chief scientist and senior policy analyst at the White House Office of Science and Technology Policy. Mr. Alexander's own research work has been in radio astronomy and space physics. He received B.S. and M.A. degrees in physics from the College of William and Mary.

BRIAN D. DEWHURST, *Co-Study Director,* joined the NRC in 2001 and is a program officer with the Aeronautics and Space Engineering Board (ASEB). Before joining ASEB, he served as a senior program associate with the Board on Physics and Astronomy. Previously, he worked with the Space Studies Board staff as a research assistant. He is a staff officer for a variety of NRC activities, including the Committee to Review NASA's Aviation Safety-related Programs and the Astro2010 Astronomy and Astrophysics Decadal Survey, among others. He received a B.A. in astronomy and history from the University of Virginia in 2000 and an M.A. in science, technology, and public policy from George Washington University in 2002.

CARMELA J. CHAMBERLAIN, adminstrative coordinator, has worked for the National Academies since 1974. She started as a senior project assistant at he Institute for Laboratory Animals for Research, which is now a board in the Division on Earth and Life Sciences, where she worked for 2 years, then transferred to the Space Science Board, which is now the SSB. She is now a program associate with the SSB.

CATHERINE A. GRUBER is an editor with the SSB. She joined the SSB as a senior program assistant in 1995. Ms. Gruber first came to the NRC in 1988 as a senior secretary for the Computer Science and Telecommunications Board and has also worked as an outreach assistant for the NAS-Smithsonian Institution's National Science Resources Center. She was a research assistant (chemist) in the National Institute of Mental Health's Laboratory of Cell Biology for 2 years. She has a B.A. in natural science from St. Mary's College of Maryland.

LEWIS GROSWALD, research associate, joined SSB as a Lloyd V. Berkner Space Policy Intern. He is a first-year graduate student pursuing his masters degree in International Science and Technology Policy at George Washington University (GW). A recent graduate of GW, he studied international affairs with a double concentration in conflict and security and Europe and Eurasia as an undergraduate. Mr. Groswald has always expressed an interest in space, but it was not until he had the opportunity to work with the National Space Society during his senior year at GW that he decided to pursue a career in space policy: educating the public on space issues and formulating policy. He also hopes to put his experience with the SSB to use fostering greater international collaboration in space.

VICTORIA SWISHER, research associate, joined the SSB in 2006. She has supported studies and workshops on the Beyond Einstein program, NASA workforce, Mars research, research enabled by the lunar environment, ITAR, and other topics. Before joining the SSB, she performed research in x-ray astronomy and laboratory astrophysics, which included studying the rays of plasma and culminated in her senior thesis, "Modeling UV and X-ray Spectra from the Swarthmore Spheromak Experiment." A graduate of Swarthmore College, she majored in astronomy and minored in English literature.

B

Statement of Task

An ad hoc committee will prepare a report to advise the nation on key goals and critical issues in 21st-century U.S. civil space policy. The committee will identify overarching goals that are important for our national interest. Issues that are critically important to achieving these goals and ensuring the future progress of the U.S. civil space program will be identified, and actions to address unresolved issues will be recommended. Using its best objective judgment and recognizing other national priorities, the committee will explore a possible long-term future for U.S. civil space activities that is built upon lessons learned and past successes; is based on realistic expectations of future resources; and is credible scientifically, technically, and politically. The committee will, inter alia

- Review the history of U.S. space policy and propose a broad policy basis for 21st-century leadership in space;
- Examine the balance and interfaces between fundamental scientific research in space, human space exploration, robotic exploration, earth observations, and applications of space technology and civil space systems for societal benefits;
- Assess the role that commercial space companies could play in fulfilling national space goals and the role of the government in facilitating the emergence and success of commercial space companies; and
- Make recommendations for government attention to address and potentially resolve problems that might prevent achieving key national goals.

Illustrative examples of potential topics for the committee's consideration in the study include the following:

- Near-term and long-term human spaceflight program goals and options for fulfilling them;
- Utility of satellites in understanding global climate change and in advancing geophysical sciences (physical oceanography, solid earth sciences, and so on), and roles and responsibilities of government agencies in such Earth observations;
- Potential opportunities in various space sciences, including planetary missions, space-based astronomy, astrophysical observations, extraterrestrial life searches, assessing planetary bodies in other solar systems, and so on;
- Reconciling total program content and total program resources for the civil space program;
- Strength of the U.S. space industrial base;
- Developing advanced technologies for applications in remote sensing and other areas;
- Access to space, availability and cost of U.S. launch vehicles, use of foreign launch capabilities; and
- International cooperation and competition in space programs.

National security space issues will not be a main focus of the report, but may be addressed to the extent that they interact with or impact the civil space program.

C

Meeting Agendas

KECK CENTER OF THE NATIONAL ACADEMIES,
WASHINGTON, D.C.
NOVEMBER 5-7, 2008

November 5, 2008

Closed Session

9:00 a.m. Committee Discussion

12:00 p.m. Lunch

Open Session

1:00 Retrospective on the History of U.S. Space Policy
- John Logsdon, National Air and Space Museum

2:00 Department of Defense Perspectives
- Ryan Henry, Deputy Under Secretary for Policy, Department of Defense

3:15 NASA Perspectives
- Michael Griffin, NASA Administrator

November 6, 2008

Closed Session

9:00 a.m. Committee Discussion

Open Session

10:00 NOAA Perspectives
- Mary Kicza, NOAA Assistant Administrator for National Environmental Satellite Data and Information Service

10: 30 Reflections on Environmental Challenges in the 21st Century
- Conrad Lautenbacher, former NOAA Administrator

11:00 Hill Perspectives
- Richard Obermann, House Science and Technology Committee
- Ken Monroe, House Science and Technology Committee

12:30 p.m. Lunch

1:30 Department of Transportation Perspectives
- George Nield, Associate Administrator for Commercial Space Transportation, Federal Aviation Administration

2:30 Panel Discussion on Space in the Eyes of the Public
- Howard McCurdy, American University
- Kathy Sawyer, Journalist and Author
- George T. Whitesides, National Space Society

4:00 International Perspectives
- Joan Johnson-Freese, U.S. Naval War College
- Kenneth Flamm, University of Texas, Austin

5:30 Adjourn for the Day

November 7, 2008

Closed Session

9:00 a.m. Committee Discussion

12:00 p.m. Meeting Adjourns

KECK CENTER OF THE NATIONAL ACADEMIES, WASHINGTON, D.C. DECEMBER 3-5, 2008

December 3, 2008

Closed Session

9:00 a.m. Committee Discussion

Open Session

12:00 p.m. Lunch

1:00 General Discussion of Study Objectives

3:00 Human Spaceflight Discussion
- Edward Lu, Google

4:00 Science and Exploration Discussion
- Joseph A. Burns, Cornell University
- Michael S. Turner, University of Chicago
- David Baltimore, California Institute of Technology
- Lennard A. Fisk, University of Michigan

5:00 Wrap-up Discussion

5:30 Adjourn for the Day

December 4, 2008

Open Session

8:30 a.m. Advanced Technology Discussion
- Charles Elachi, Jet Propulsion Laboratory
- Raymond S. Colladay, Lockheed Martin Corporation (retired)
- Jay Apt, Carnegie Mellon University

10:00 Earth Observations Discussion
- Anthony Janetos, University of Maryland
- Art Charo, National Research Council Staff
- Thomas H. Vonder Haar, Colorado State University

11:00	Foreign Policy Discussion • Leon Fuerth, George Washington University
12:00 p.m.	Workforce and STEM Education Discussion [working lunch] • Natalie Crawford, RAND Corporation • George Muellner, American Institute of Aeronautics and Astronautics
1:00	Entrepreneurial Space Industry Discussion • Elon Musk, SpaceX
2:00	General Discussion
3:00	Beyond the Moon: A New Roadmap for Human Space Exploration in the 21st Century • Lou Friedman, The Planetary Society
3:45	MIT Space, Policy, and Society Research Group Study • David Mindel, Massachusetts Institute of Technology
4:30	National Security Discussion • Keith Hall, Booz Allen Hamilton • Gary Payton, Department of Defense
5:30	Adjourn for the Day

December 5, 2008

Closed Session

9:00 a.m.	Committee Discussion
5:00 p.m.	Meeting Adjourns

KECK CENTER OF THE NATIONAL ACADEMIES,
WASHINGTON, D.C.
JANUARY 13-15, 2009

January 13, 2009

Closed Session

8:30 a.m. Committee Discussion

Open Session

9:30 Report on Office of Management and Budget Visit
- Lester L. Lyles, Consultant, Lyles Group (U.S. Air Force, retired)
- James B. Armor, Jr., Consultant (U.S. Air Force, retired)

10:15 Public Interest and Attitudes about Space Exploration
- Neil Tyson, Hayden Planetarium

11:15 Commercial Space and Economics Panel
- Carissa Christensen, The Tauri Group, LLC
- Pierre Chao, Center for Strategic and International Studies and Renaissance Strategic Advisors
- Kenneth S. Flamm, University of Texas at Austin

12:30 p.m. Lunch

1:00 General Discussion

2:00 Thoughts on the Future of Space Exploration
- Buzz Aldrin, former NASA Astronaut (U.S. Air Force, retired)

3:15 NRC Report on *National Security Controls on Science and Technology in a Globalized World*
- Patricia Wrightson, National Research Council Staff

4:00 Lessons Learned from 1991 Space Policy Report Implications of the *Gathering Storm* Report (via telecom)
- Norman Augustine, Lockheed Martin (retired)

5:30 Adjourn for the Day

January 14, 2009

Closed Session

8:30 a.m. Committee Discussion

5:00 p.m. Adjourn for the Day

January 15, 2009

Closed Session

8:30 a.m. Committee Discussion

4:00 p.m. Meeting Adjourns

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Committee Outreach and Public Responses

INPUT SOLICITED FROM THE PUBLIC

Over the course of the study, the committee maintained a public website[1] to provide information on the study's task, meeting dates, agendas, and other relevant items and to provide a means for public comments for the committee's attention. In addition, comments from the public were solicited through an online survey that asked responders to provide their full names and e-mail address, and to consider the following:

> The committee invites you to share your views with the study committee by responding to the questionnaire below. Questions that you might consider when framing your input to the committee:
>
> - What should be the rationale and goals for the civil space program?
> - How can the civil space program address key national issues?
>
> For the purposes of this study, the U.S. civil space program encompasses activities from NASA, NOAA, FAA, and the commercial space sector.

The questionnaire was announced on Facebook.com, NASAWatch.com,[2] Slashdot.org,[3] and Leonard David's blog at space.com.[4] The public was asked to keep replies to a maximum of 600 words. The committee also sought a range of

[1] Available at http://www7.nationalacademies.org/ssb/rationale_goals_civil_space.html.
[2] Available at http://www.nasawatch.com/archives/2009/01/nasa_seeks_publ.html.
[3] Available at http://science.slashdot.org/article.pl?sid=09/01/07/2130209.
[4] Available at http://www.space.com/news/090112-us-space-program-survey.html.

perspectives by inviting a number of outside experts to brief the committee on their views about future directions of the civil space program. See Appendix C for meeting agendas, which identify all briefings to the committee.

Additionally, research associates from diverse disciplines at the National Academies were invited to share their thoughts during a meeting with the committee staff. The perspectives from the research associates, who tend to be younger early-career professionals with an interest in science and technology policy, were shared with the committee.

THE RESPONSES

In total, approximately 1,600 people responded to the committee's survey, either officially through the survey form or as a comment on one of the websites previously mentioned, and the committee was impressed with the thought and care reflected in the responses. The committee regarded the responses as a useful gauge of community interest but thought that because the survey was informal, detailed analysis would most likely be misleading. Submissions almost uniformly reflected deep thought about and serious attention to the issues considered by the study. Responses rarely focused on a single aspect of space policy and instead tended to address many ideas.

Many respondents expressed frustration with the current course of the program, but at the same time they expressed hope for the future of the U.S. space program. Some typical examples follow:

> The space shuttle has killed 14 brave astronauts in two awful accidents—where is the upside of that program?

> NASA should be research and exploration, not a poor implementation of Amtrak for Space.

> At the current rate, CNN will be reporting the 1st landing of astronauts on Mars simply because CNN is going to beat NASA to Mars with astronauts of their own.

> NASA has become counter-productive because it's doing the same thing now it was doing forty years ago, which never quite motivates people to be inventive or innovative—just structured and regulatory. NASA should be almost exclusively focused on things like deep space exploration, manned interplanetary travel, etc., which don't have an immediate commercial benefit.

> In my view, the only rational thing that I can conceive of is for the President to announce and redefine the goals of NASA.

There were four dominant themes, as follows:

1. Climate change and Earth monitoring ["This generation is not racing to the moon, we are fighting for the very ability to continue to live as we do on this planet"];
2. Using NASA to stimulate and enable commercial efforts;
3. Civil space as a necessary driver of the science and engineering fields; and
4. Space colonization ["If there is a rationale for manned activities in space, I believe the only logical one is to enable self-sustaining human habitation off the Earth's surface"].

Respondents were also concerned about

5. Developing low-cost launch capabilities; protecting against near-Earth objects;
6. Increasing education and public outreach;
7. Using NASA to provide more jobs during this economic downturn ["Development of space-related infrastructure and industries can become the best tool to get America and the rest of the world out of the current economic recession"];
8. NASA investigating new energy sources, and the fact that NASA's efforts often result in so-called "spin-off" technologies; and
9. The future of human spaceflight ["a coherent and sustainable policy framework for NASA human spaceflight . . . is desperately needed"].

In general, the responses also strongly linked national pride with the space program and reflected the concept that space exploration was good for humanity.

> I believe that NASA in particular embodies an inalienable and indelible part of what it means to be an American. These are clearly difficult financial times, but shall we tell our children that we stopped being world leaders in science and exploration because it was too expensive to do so? Let us continue to explore, to discover, and to lead the world into the future the way America always has since the first shot of the American Revolution made us who we are.

RESPONSES FROM PROFESSIONAL SOCIETIES

In response to an invitation to provide comments on the study, the American Geological Institute (AGI), the American Society for Gravitational and Space Biology (ASGSB), the National Space Society, and Space Florida submitted comments.

The AGI's responses focused on Earth observations from space.

> It is absolutely critical that the U.S. Civil Space Program conduct global to local Earth observations from the surface to the atmosphere to space with direct sampling of the land, sea and air, plus observations from airplanes, balloons and satellites. It is equally essential that many of these observations be conducted over appropriate time scales without time gaps and that the government-led infrastructure be maintained, modernized or developed as needed. Computer modeling, data archiving and data accessibility are other key factors that make for a complete, competent and cost-effective program.

The AGI expressed concern that the civil space program is "woefully underfunded" and mentioned its strong support for the NRC decadal survey *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond.*[5] The AGI concluded by noting

> In conclusion, the geoscience community is directly and indirectly reliant on the U.S. Civil Space Program for jobs, data, analysis, research, applications, training and teaching. There is no program in the U.S. or elsewhere that could replace the Civil Space Program and the past work of the program must be maintained in the public domain for its scientific, historical, cultural and societal value.

The ASGSB considered the following issues to be important for committee consideration: restoring space biology's identity as a budget item; restoring research funding for the International Space Station; restoring NASA funding for basic research; recognizing that decreased funding in space life sciences research has led to severed links in academia; and recognizing the need for basic animal and plant research in space. The ASGSB remarked

> Our society of ~350 professionals and students from universities, government, and industry represents the core community with a mission to work closely with NASA to create and disseminate knowledge about how living organisms respond to gravity and the spaceflight environment. This knowledge provides key insights into normal and abnormal cell function and organism physiology that cannot be observed using traditional experimental approaches on Earth, and serves as a venue for breakthrough biomedical and biotechnological discoveries to advance human exploration of space and improve quality of life for the general public.

The National Space Society sent as its response a 16-page statement made by its executive director, George T. Whitesides,[6] on May 7, 2008, before the Senate

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[5] National Research Council, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond,* The National Academies Press, Washington, D.C., 2007.

[6] Mr. Whitesides was appointed to the Committee on the Rationale and Goals of the U.S. Civil Space Program, but resigned on November 18, 2008, due to a conflict that arose between his profes-

Subcommittee on Space, Aeronautics and Related Sciences of the Committee on Commerce, Science, and Transportation. The statement addresses several themes: space is linked to education, energy, and security; it is vital that the space program continue to support and nurture its industrial base; and international collaboration can strengthen economic and national security. The testimony recommended that human and robotic exploration be more explicitly linked to climate- and energy-related needs on Earth and that NASA strengthen its use of commercial space services. Mr. Whitesides' testimony expressed concern about the looming gap in human spaceflight capability.

> The consequences of the gap, as seen during the transition between Apollo and Shuttle, are well known and ominous. Loss of funding translates into a loss of NASA's most critical assets: the knowledge, corporate memory, and hands-on skills of its people. With a loss of jobs comes a loss of economic vitality in communities like Brevard County, Florida, and New Orleans, Louisiana, as people move away to look for jobs and take their money and families with them. Once those people are gone, restoring diminished capabilities and communities will not be as simple as issuing a call-back after a brief layoff.

Space Florida's input to the committee focused on optimizing the use of the International Space Station, leveraging partnerships between NASA and other government, commercial, and space advocacy organizations. Space Florida strongly supports the Constellation program and human space exploration, and they believe that the crisis in science, technology, engineering, and mathematics (STEM) education needs to be addressed immediately:

> Finally, all of the above will be difficult to achieve if America does not address its crisis in STEM education. We all know the numbers too well, e.g., both China and India producing many times over the number of new engineering graduates with STEM degrees than the U.S. does annually. If not addressed immediately, the consequences for the future competitiveness of the U.S. Space Program, and America's technology innovation are at risk. While it is unrealistic to expect the Space Program to be the solution to this crisis, it can and should play an important role by encouraging more students to enter STEM related careers and technological innovation across the entire Civil Space enterprise (as opposed to reuse/modification of technology developed, in some cases, more that 40 years ago).

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sional circumstances and the work of the committee. The call for public input and the National Space Society's response was well after Mr. Whitesides' resignation.