NASA's Strategic Direction and the Need for a National Consensus

Committee on NASA's Strategic Direction

Division on Engineering and Physical Sciences

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Preface

The National Aeronautics and Space Administration (NASA) is widely admired for astonishing accomplishments since its formation in 1958. These include, for example, setting the (still-standing) world speed record for a piloted aircraft (1967), landing 12 humans on the Moon and returning them safely to Earth (1969 to 1972), exploring all giant planets with Voyager (launched in 1976, still operating), launching the (still-operating) Hubble Space Telescope (1990), establishing the International Space Station (2010), and achieving the soft-landing on Mars of an automobile-sized robotic rover (2012). These missions and many others have dramatically changed our understanding of our universe, our solar system, and our planet. This list constitutes only a small sample of NASA successes over its half-century history.

Looking ahead over a comparable period of time, what can the United States and the world expect of NASA? What will be the agency's goals and objectives, and what will be the strategy for achieving them? More fundamentally, how and by whom will the goals, objectives, and strategy be established and subsequently modified to reflect changes in science, technology, national priorities, and available resources?

In late 2011, the Congress directed the NASA Office of Inspector General to commission a "comprehensive independent assessment of NASA's strategic direction and agency management." Subsequently, NASA requested that the National Research Council (NRC) conduct this independent assessment. In the spring of 2012, the NRC Committee on NASA's Strategic Direction was formed and began work on its task. (The full statement of task appears in Appendix A.)

The committee was charged to address the evolution of NASA's goals, objectives, and strategies, including in particular those set forth in the *2011 NASA Strategic Plan*; the relevance of NASA's strategic direction to achieving national priorities; the viability of NASA's plans in the context of constrained budgets consistent with continuing deficit reduction; the appropriateness of resource allocations among NASA's various programs; NASA's organizational structure and potential changes to improve efficiency and effectiveness; and ways in which NASA could establish and effectively communicate a common unifying vision of the future that encompasses the agency's full array of missions. It is worth noting that the committee was *not* asked to opine on what should be NASA's goals, objectives, and strategy. Neither was it expected to provide a comprehensive summary of past work that was relevant to NASA's strategic direction. Rather, the committee was asked for recommendations on how the goals might best be established and communicated, and that is indeed the focus of this report.

The 12-member committee met as a group five times—three meetings in Washington, D.C.; one in Irvine, California; and one in Los Angeles, California. (See Appendix B for a list of meetings and site visits.) At these meetings, the committee was informed by presentations and materials provided by a number of current and former NASA officials, by officials from other relevant U.S. government agencies, by non-government experts on space policy, and by representatives of the U.S. aerospace industry.

In addition, each of NASA's 10 field centers was visited by members of the committee who met with each center's leadership and with groups of employees. The committee also received almost 800 inputs from various stakeholders and the general public by means of a web-based system for soliciting and receiving comments.

All of this, plus the committee's deliberations on the substance of its potential findings, conclusions, and recommendations, and on the text of this consensus report, was accomplished over a period measured in months rather than years. I want to express my appreciation to the vice chair of the committee, Ron Sega, and to our fellow committee members for the time, effort, and expertise they brought to this intense, expedited study. Their dedication to this project stems largely from their enthusiastic appreciation of the importance of the nation's aeronautics and space programs.

Essential contributions to this effort were made by knowledgeable and skilled members of the NRC staff. Dwayne Day and Michael Moloney played central roles in organizing, supporting, and contributing to the study. Alan Angleman, David Smith, Amanda Thibault, Danielle Piskorz, and Andrea Rebholz also made important substantive contributions, and Linda Walker provided valuable administrative support. I am grateful to all.

Albert Carnesale, *Chair*
Committee on NASA's Strategic Direction

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 Report Review Committee of the National Research Council (NRC). The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Wanda M. Austin, The Aerospace Corporation,
Vinton G. Cerf, Google, Inc.,
Mary-Lynn Dittmar, Dittmar Associates, Inc.,
Thomas R. Gavin, Jet Propulsion Laboratory California Institute of Technology,
David Goldston, Natural Resources Defense Council,
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Thomas S. Moorman, Jr., Booz Allen Hamilton,
Gregory H. Olsen, GHO Ventures, LLC,
George H. Rieke, University of Arizona, and
Richard H. Truly, National Renewable Energy Laboratory (retired).

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 Martha P. Haynes, Cornell University, and Louis J. Lanzerotti, New Jersey Institute of Technology. Appointed by the NRC, they were 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.

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Summary

The National Aeronautics and Space Administration (NASA) is at a transitional point in its history and is facing a set of circumstances that it has not faced in combination before. The agency's budget, although level-funded in constant-year dollars, is under considerable stress, servicing increasingly expensive missions and a large, aging infrastructure established at the height of the Apollo program. Other than the long-range goal of sending humans to Mars, there is no strong, compelling national vision for the human spaceflight program, which is arguably the centerpiece of NASA's spectrum of mission areas. The lack of national consensus on NASA's most publicly visible mission, along with out-year budget uncertainty, has resulted in the lack of strategic focus necessary for national agencies operating in today's budgetary reality. As a result, NASA's distribution of resources may be out of sync with what it can achieve relative to what it has been asked to do.

NASA now faces major challenges in nearly all of its primary endeavors—human spaceflight, Earth and space science, and aeronautics. While the agency has undertaken new efforts to procure commercial transportation to resupply the International Space Station (ISS) and has also initiated an effort to commercially procure crew transportation as well, the agency currently lacks a means of launching astronauts on a U.S. spacecraft to Earth orbit, where the agency operates the ISS, which was built at considerable time, effort, and expense.

Although gaps in U.S. human spaceflight capability have existed in the past, several other factors, in combination, make this a unique period for NASA. These include a lack of consensus on the next steps in the development of human spaceflight, increasing financial pressures, an aging infrastructure, and the emergence of additional space-capable nations—some friendly, some potentially unfriendly. In addition, U.S. leadership in space science is being threatened by insufficient budgets to carry out the missions identified in the strategic plans (decadal surveys) of the science communities, rising cost of missions, decreasing science budgets, and the collapse of partnerships with the European Space Agency (ESA)—this at a time when others (most notably ESA and China) are mounting increasingly ambitious space programs. Finally, NASA's aeronautics budget has been reduced to the point where it is increasingly difficult for the agency to contribute to a field that U.S. industry and the national security establishment have long dominated.

These problems are not primarily of NASA's doing, but the agency could craft a better response to the uncertainty, for example, by developing a strategic plan that includes clear priorities and a transparent budget allocation process. A better response would improve NASA's ability to navigate future obstacles and uncertainties. An effective agency response is vital, because at a time when the strategic importance of space is rising and the capabilities of other spacefaring nations are increasing, U.S. leadership is faltering.

For the United States to be a leader in space, as required by the 1958 National Aeronautics and Space Act, it must be a country with bold ideas, science and engineering excellence, and the ability to convince others to work with it in the pursuit of common goals. Leadership depends on the perception of others that whoever is in the lead knows the way forward, is capable of forging the trail, and is determined to succeed despite inevitable setbacks. It does not mean dominance. Those who join are partners, not followers, and partnerships must be equitable, with all voices being heard.

Leadership is more nuanced today than during the Cold War rivalry with the Soviet Union over which country would achieve the next space "first." Countries that once depended on partnerships with

the United States to execute their space programs now have other choices, including going it alone. If the United States is to continue to maintain international leadership in space, it must have a steady, bold, scientifically justifiable space program in which other countries want to participate, and, moreover, it must behave as a reliable partner.

Despite decades of U.S. leadership and technical accomplishment, many of these elements are missing today. Abrupt changes in the goals the United States is pursuing for human spaceflight, coupled with concerns about U.S. unreliability in key international partnerships, can erode this country's leadership position. The thrilling Mars Curiosity mission may be a testament to U.S. leadership in robotic space exploration today, but the sudden and dramatic proposed cut to the Mars exploration budget and withdrawal from the ExoMars program with Europe cast doubt on the future. Human spaceflight capabilities historically have served as a symbol of a country's leadership in space. This multi-year period when the United States cannot launch humans into space, requiring reliance on Russia for access to the International Space Station, further undermines any claim to leadership despite the programmatic success of the development of the ISS, which is, in fact, led by the United States.

THE COMMITTEE ON NASA'S STRATEGIC DIRECTION

In late 2011, the Congress directed NASA's Office of Inspector General to commission a "comprehensive independent assessment of NASA's strategic direction and agency management." Subsequently, NASA requested that the National Research Council (NRC) conduct this independent assessment. In the spring of 2012, the NRC Committee on NASA's Strategic Direction was formed and began work on its task.

The statement of task for this study appears in Appendix A (and is summarized in the Preface). Notably, the committee was *not* asked to deliberate on what should be NASA's goals, objectives, and strategy; rather, it was asked for recommendations on how these goals, objectives, and strategy might best be established and communicated.

HUMAN SPACEFLIGHT

The committee has seen little evidence that a current stated goal for NASA's human spaceflight program—namely, to visit an asteroid by 2025—has been widely accepted as a compelling destination by NASA's own workforce, by the nation as a whole, or by the international community. On the international front there appears to be continued enthusiasm for a mission to the Moon but not for an asteroid mission, although there is both U.S. and international interest in robotic missions to asteroids. This lack of consensus on the asteroid-first mission scenario undermines NASA's ability to establish a comprehensive, consistent strategic direction that can guide program planning and budget allocation. While the committee did not undertake a technical assessment of the feasibility of an asteroid mission, it was informed by several briefers and sources that the current planned asteroid mission has significant shortcomings.

The asteroid mission is ostensibly the first step toward an eventual human mission to Mars. A human mission to Mars has been the ultimate goal of the U.S. human spaceflight program. This goal has been studied extensively by NASA and received rhetorical support from numerous U.S. presidents, and has been echoed by some international space officials, but it has never received sufficient funding to advance beyond the rhetoric stage. Such a mission would be very expensive and hazardous, which are the primary reasons that such a goal has not been actively pursued.

There also is no national consensus on what would constitute an appropriate mix of NASA's capability-driven and mission-driven programs. While a capabilities-driven approach may be the most reasonable approach given budget realities, such an approach still has to be informed by a clear, consistent, and constant path to the objective.

EARTH AND SPACE SCIENCE

NASA has clearly demonstrated the success of the strategic planning process for Earth and space science that is founded on the NRC's decadal surveys (NRC, 2007; a decadal survey on life and microgravity science [NRC, 2011a] has also been produced for the Human Exploration and Operations Mission Directorate). The decadal survey process has matured into a robust method for developing a set of goals and objectives for various programs that are based on a community consensus on an achievable suite of science programs in pursuit of high-priority, compelling science questions. However, even the best strategic plan is vulnerable to severe changes in the assumptions that underlie its development, whether those changes are applied internally or externally. As an example, the recent set of surveys on astronomy and astrophysics (NRC, 2010) and planetary science (NRC, 2011b) were based on budget projections provided to the relevant decadal committees, and now these projections exceed the current budget as well as current budget projections. Rising costs associated with increasingly complex missions, declining science budgets, international partnerships that fell apart, and mission cost overruns have strained science budgets to their breaking point. As a result, key decadal priorities in astrophysics, planetary science, and Earth science will not be pursued for many years, or not at all. The carefully crafted strategic planning process, with its priority setting and consensus building, which has led in the past to the United States leading the world with science missions such as the Curiosity rover on the surface of Mars and the Hubble Space Telescope, is now in jeopardy because it no longer may lead to a tangible program outcome.

AERONAUTICS

The NASA aeronautics program has made important contributions to national priorities related to the U.S. air transportation system, national defense, and those portions of the space program that include flight through Earth's atmosphere. However, the budget for NASA's aeronautics program shrank significantly in the 2000-2010 decade, and the full historically demonstrated potential of the aeronautics program is not being achieved given the current levels of funding. During the course of its deliberations, the committee did not hear a clear rationale for the overall decline in NASA aeronautics spending during the past 15 years.

TECHNOLOGY DEVELOPMENT

Because of the unique nature of most of its missions, NASA has had a number of very specific technological requirements in areas ranging from expendable and reusable launch vehicles to deep-space propulsion systems to radiation protection for astronauts, and much more. The recently established Space Technology Program has carried out a roadmapping and priority-setting strategic planning process for such technologies, assisted by the NRC, but the program is yet to be funded at the levels requested by the President's budget.

BUDGETS AND BALANCE

The funding for NASA's total budget has been remarkably level in constant-year dollars for more than a decade. However, there has been some instability at the programmatic level and the out-year projections in the President's budget are unreliable, which makes it difficult for program managers to plan activities that require multi-year planning. Put another way, although the budget may have been level over time, NASA experienced substantial program instability over the same period. Numerous times the agency initiated new programs with the *expectation* that budgets would increase to support them (a basic requirement for optimizing any development program's budget), only to have no increases emerge. Taken in aggregate, this situation has been wasteful and inefficient. Even leaving aside the funding requirements for large procurements, it is tempting to assume that if NASA officials knew to expect a flat budget they could plan better, but in several recent cases they were told (even required) to expect funding that never ultimately emerged.

Last, flat budgets historically have not allowed NASA to pursue major initiatives in human spaceflight; see Figures 1.4 and 1.5, where the budget bumps for Apollo and the space shuttle/ISS programs are apparent.

NASA cannot execute a robust, balanced aeronautics and space program given the current budget constraints. For example, major components needed for future human exploration (including important life sciences experiments on the ISS) are not currently in the budget; high-priority science missions (including robotic planetary exploration missions that are precursors to human exploration) identified in the most recent NRC decadal survey are unfunded; and aeronautics now accounts for only about 3 percent of the total NASA budget. In addition, individual NASA centers are finding it necessary to selectively reduce their infrastructure or find alternative ways to support it (e.g., through external collaborations). External partnerships can be highly beneficial, especially in the current fiscally constrained environment, and may enable NASA to execute a robust and balanced aeronautics and space program without additional funds. However, coordination and integration of such activities for the overall benefit of NASA are both essential for success.

Because of legislative and regulatory limitations, NASA officials lack flexibility in how to manage the agency in terms of personnel and facilities, a factor contributing to the mismatch between budget and mission. With the current available-budget-driven approach, intermediate milestones and completion dates for some programs have been delayed. This in turn results in a lack of tangible near-term performance outcomes from cost-inefficient programs that by nature must accommodate increases in fixed and indirect costs. Delays also have a deleterious effect on mission performance; stretching programs out limits opportunities for NASA to develop and incorporate new technology into program architectures defined years before.

There is a significant mismatch between the programs to which NASA is committed and the budgets that have been provided or anticipated. The approach to and pace of a number of NASA's programs, projects, and activities will not be sustainable if the NASA budget remains flat, as currently projected. This mismatch needs to be addressed if NASA is to efficiently and effectively develop enduring strategic directions of any sort.

To reduce the mismatch between the overall size of its budget and NASA's current portfolio of missions, facilities, and personnel, the White House, Congress, and NASA, as appropriate, could use any or all of the following four (non-mutually exclusive) options. The committee does not recommend any one option or combination of options but presents these to illustrate the scope of decisions and tradeoffs that could be made. Regardless of the approach or approaches selected, eliminating the mismatch will be difficult.

Option 1. Institute an aggressive restructuring program to reduce infrastructure and personnel costs to improve efficiency.

Option 2. Engage in and commit for the long term to more cost-sharing partnerships with other U.S. government agencies, private sector industries, and international partners.

Option 3. Increase the size of the NASA budget.

Option 4. Reduce considerably the size and scope of elements of NASA's current program portfolio to better fit the current and anticipated budget profile. This would require reducing or eliminating one or more of NASA's current portfolio elements (human exploration, Earth and space science, aeronautics, and space technology) in favor of the remaining elements.

Each of the above sample options, with the possible exception of Option 2, would require legislative action. Every option except for Option 3 would require substantial changes within NASA in order to substantially address the mismatch between NASA's programs and budget. Before implementation of any such options, the advantages and disadvantages, including possible unintended consequences, would deserve careful consideration. For example, if not handled carefully, Option 1 could constrain future mission options or increase future mission costs if unique facilities needed by future missions were decommissioned. Option 1 might also diminish NASA's workforce capabilities if changes in policies prompt large numbers of key personnel to retire or seek other employment. To be effective, Option 2 might require congressional authorization for NASA to make long-term financial commitments to a particular program to assure prospective partners that neither NASA nor the Congress would unilaterally cancel a joint program. Option 3, of course, is ideal from NASA's perspective, but its selection also seems unlikely given the current outlook for the federal budget. Option 4 is perhaps the least attractive, given the value of each major element in NASA's portfolio.

The committee has identified significant impacts of current budget constraints on the individual programs at NASA and has described the kinds of options that would have to be considered to address the mismatch between the scope of NASA's programs and budget. It has not attempted to judge the appropriateness of the budget distribution among these programs internal to the agency. Moreover, it would have been difficult to do so because of the absence of stated priorities that would provide a framework for making that assessment. In addition, the committee notes that it was not asked to set those kinds of agency-wide priorities.

The foregoing observations (and the detailed discussions in the body of this report) lead the committee to reach the following conclusions and offer the related recommendations:

> **Conclusion:** There is no national consensus on strategic goals and objectives for NASA. Absent such a consensus, NASA cannot reasonably be expected to develop enduring strategic priorities for the purpose of resource allocation and planning.
>
> **Recommendation:** The administration should take the lead in forging a new consensus on NASA's future that is stated in terms of a set of clearly defined strategic goals and objectives. This process should apply both within the administration and between the administration and Congress and should be reached only after meaningful technical consultations with potential international partners. The strategic goals and objectives should be ambitious, yet technically rational, and should focus on the long term.
>
> **Recommendation:** Following the establishment of a new consensus on the agency's future, NASA should establish a new strategic plan that provides a framework for decisions on how the agency will pursue its strategic goals and objectives, allows for flexible and realistic implementation, clearly establishes agency-wide priorities to guide the allocation of resources within the agency budget, and presents a comprehensive picture that integrates the various fields of aeronautics and space activities.
>
> **Recommendation:** NASA's new strategic plan, future budget proposals prepared by the administration, and future NASA authorization and appropriation acts passed by Congress should include actions that will eliminate the current mismatch between NASA's budget and its portfolio of programs, facilities, and staff, while establishing and maintaining a sustainable distribution of resources among human spaceflight, Earth and space science, and aeronautics, through some combination of the kinds of options identified above by the committee. The strategic plan should also address the rationale for resource allocation among the strategic goals in the plan.

Recommendation: NASA should work with other U.S. government agencies with responsibilities in aeronautics and space to more effectively and efficiently coordinate the nation's aeronautics and space activities.

Conclusion: The NASA field centers do not appear to be managed as an integrated resource to support the agency and its strategic goals and objectives.

Conclusion: Legislative and regulatory limitations on NASA's freedom to manage its workforce and infrastructure constrain the flexibility that a large organization needs to grow or shrink specific scientific, engineering, and technical areas in response to evolving goals and budget realities.

Although the committee carefully analyzed NASA's current strategic plan, as well as previous ones, it ultimately concluded that the strategic planning process is affected more by what happens outside the agency than by any process inside NASA. The lack of a national consensus on what NASA should do constrains NASA's ability to plan and to operate.

The committee recognizes that it lacked the capability and time to conduct a detailed supporting analysis and to make specific recommendations for changes in the current NASA infrastructure. However, the committee offers a path forward for NASA to follow, in close collaboration with the President and Congress.

Recommendation: With respect to NASA centers:

The administration and Congress should adopt regulatory and legislative reforms that would enable NASA to improve the flexibility of the management of its centers. NASA should transform its network of field centers into an integrated system that supports its strategic plan and communications and advances its strategic goals and objectives.

Today it is common to declare that all future human spaceflight or large-scale Earth and space science projects will be international. Many U.S. leaders also assume that the United States will take the lead in such projects. However, American leadership in international space cooperation requires meeting several conditions. First, the United States has to have a program that other countries want to participate in, and this is not always the case. Second, the United States has to be willing to give substantial responsibility to its partners. In the past, the approach of the United States to international partnership has too often been perceived as being based on a program conceived, planned, and directed by NASA. Third, other nations must be able to see something to gain—in other words, a reason to partner with the United States. Finally, the United States has to demonstrate its reliability and attractiveness as an international partner.

The capabilities and aspirations of other nations with respect to space have changed dramatically since the early days of the space race between the Soviet Union and the United States. One of the most important successes of the ISS was its international character and the role of the United States as the managing partner in a global enterprise. If the United States does seek to pursue a human mission to Mars, such a mission will undoubtedly require the efforts and financial support of many nations.

Recommendation: The United States should explore opportunities to lead a more international approach to future large space efforts both in the human space program and in the science program.

In preparing this report, the committee held three meetings at which current and former NASA leaders, representatives of other government agencies, academics, and historians shared their views of the origin and evolution of NASA and its programs and the issues facing the agency today. The committee received input from nearly 800 members of the public through a Web-based questionnaire, and small groups of committee members visited each of the nine NASA field centers and the Jet Propulsion Laboratory. Furthermore, the committee reviewed a large number of studies conducted by the NRC and other groups over the decades that made recommendations about the conduct of NASA's programs and the agency's future, as well as NASA's strategic plans back to 1986.

The committee was impressed with the quality of personnel and the level of commitment of the agency's civil service and contractor staffs and the superb quality of the work done by the agency in general, most notably recently demonstrated by the Curiosity landing on Mars. But the committee also heard about frustration with the agency's current path and the limitations imposed on it by the inability of the national leadership to agree on a long-term direction for the agency. Only with a national consensus on the agency's future strategic direction, along the lines described in this report, can NASA continue to deliver the wonder, the knowledge, the national security and economic benefits, and the technology typified by its earlier history.

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1
NASA's Past and Current Trajectory

According to prior National Research Council (NRC) studies, establishing and maintaining strong NASA programs in space and aeronautics will enhance national economic vitality, public well-being, scientific knowledge, and national security (NRC, 2006; NRC, 2009). As a result, these studies assert, the vitality of NASA programs is a national imperative that will grow in importance in the future.

To date, space exploration by humans has scarcely intruded into the infinite expanse beyond the limits of planet Earth. Scientific instruments, on the surface or in orbit around Earth and other bodies in the solar system—and other probes that have passed by one or more bodies as they tour the solar system—have enabled U.S. scientists to carefully examine vast regions of space with ever greater perception, answering old questions and raising new ones about the past, present, and future of the universe. Earth orbit also provides an excellent vantage point for spacecraft to examine Earth and its biosphere, collecting scientific data or providing valuable services such as direct broadcasting, satellite communications, weather observations, and other types of surveillance for military, commercial, and civil purposes. In addition, long-term aeronautical research and development has provided enormous benefits in the development of safe and efficient commercial as well as military air vehicles.

NASA was created in the midst of the Cold War as a multi-purpose agency to pursue goals in robotic and human spaceflight and to build on aeronautics technology development begun over several decades by the National Advisory Council on Aeronautics (NACA). NASA quickly acquired or built substantial infrastructure and space capabilities at various locations throughout the United States because these capabilities, primarily test facilities, did not already exist in industry. The largest of NASA's many missions over the past half-century has been the pursuit of human spaceflight, and approximately half of the agency's current budget is devoted to this pursuit. NASA's Earth and space science and aeronautics missions have received smaller amounts of funding—currently science is approximately 29 percent, aeronautics is approximately 3 percent, and technology is also approximately 3 percent. Historically, science was a significantly smaller percentage of the budget than it is today, although starting in the 1990s the percentage of NASA's budget devoted to Earth and space science grew, and in the 2000s the aeronautics budget shrank.

Human spaceflight goals have generally been established by presidential policy, subject to congressional authorization and appropriations. The goal of human spaceflight has itself changed over the years. During the 1960s the ultimate purpose was geopolitical, to compete against the Soviet Union and demonstrate U.S. technological prowess on an international stage. During the 1970s the purpose was to reduce the cost of launching spacecraft to orbit and to develop routine operations for humans in space. By the 1980s, the goal had become to develop a space station with Western allies. By the 1990s this goal had evolved to include engagement with post-Cold War Russia. Since the early 1970s human spaceflight has been confined to low Earth orbit.

Earth and space science goals are ostensibly established in the decadal survey process led by the NRC, a process that has been highly successful at developing priorities in Earth and space sciences and leading to their eventual implementation. This process has been under strain in recent years. Some projects, such as the James Webb Space Telescope, have run over budget, the administration has rejected the proposed planetary science program and has also postponed work on a key element of the astronomy community's decadal survey. Although it is beyond the scope of this report to recommend ways of improving the decadal survey process, the committee notes that at the time this report was being finalized, the NRC was undertaking a workshop to identify lessons learned from past decadal surveys, including ways in which they might be improved.

NASA's aeronautics program budget is currently approximately 3 percent of the overall agency's budget, hardly reflective of a strategic imperative. Over the decades, the goals for aeronautics have ranged from efficient subsonic fixed-wing aircraft to high-speed civil transport systems to hypersonic airbreathing engines for multiple-stage-to-orbit space access.

NATIONAL AERONAUTICS AND SPACE ACT OF 1958 AND ITS EVOLUTION

The focus of NASA on aeronautics and space dates back to its founding, when the National Aeronautics and Space Act of 1958 transformed the NACA into NASA. The act specified that NASA shall plan, direct, and conduct aeronautical and space activities to increase scientific knowledge, to support the development of advanced aircraft, to develop and operate advanced spacecraft, to consult with the Department of Defense (DOD) and other federal agencies regarding matters of mutual interest, to strongly encourage commercial activities in space, and to ensure that the United States remains a leader in aeronautics and space. For example, the first launch of a NASA spacecraft is shown in Figure 1.1. The act has been modified by Congress many times over the years, often upon presidential recommendation. This section describes some of the key changes.

FIGURE 1.1 Thor-Able I with the Pioneer I spacecraft atop, prior to launch at Eastern Test Range at what is now Kennedy Space Center. Pioneer I launched on October 11, 1958, the first spacecraft launched by the 11-day-old National Aeronautics and Space Administration. Although the spacecraft failed to reach the Moon, it did transmit 43 hours of data. SOURCE: NASA.

In 1973 the provisions for the National Aeronautics and Space Council, which was set up in 1958 to coordinate among the nation's space and aeronautics agencies while contributing to the national space policy, was deleted from the National Aeronautics and Space Act along with its functions after President Nixon abolished the council in an executive reorganization plan. This body was later resurrected as the National Space Council in the 1989 NASA Authorization Act. The council was used by President George H.W. Bush, but Presidents Bill Clinton, George W. Bush, and Barack Obama neither funded nor staffed the National Space Council.

In 1984 Earth science was formally added as one of NASA's objectives. In addition, the act was modified to mandate that NASA "seek and encourage, to the maximum extent possible, the fullest commercial use of space."

In 1990, NASA support of the commercial use of space was strengthened by the addition of requirements that NASA "encourage and provide for Federal Government use of commercially provided space services and hardware, consistent with the requirements of the Federal Government."

EVOLUTION OF NASA'S VISION AND MISSION STATEMENTS

Throughout its history, NASA has continually modified the statements of its vision and mission. It is not clear whether these changes reflected substantive changes in the evolution of NASA's strategic thinking over time, or simply reflected other, less substantial issues. In any event, a comparison of the different statements over time reveals some interesting changes. Consider the following statements of the agency's "vision"

1986: NASA's vision is to be at the forefront of advancements in aeronautics, space science, and exploration.

1992: NASA is committed to the future. As explorers, pioneers and innovators, we boldly expand frontiers in air and space to inspire and serve American and to benefit humanity.

1994-2000: NASA is an investment in America's future. As explorers, pioneers, and innovators, we boldly expand frontiers in air and space to inspire and serve America and to benefit the quality of life on Earth.

2003: To improve life here, To extend life to there, To find life beyond.

2006: To advance U.S. scientific, security, and economic interests through a robust space exploration program.

2011: To reach for new heights and reveal the unknown, so that what we do and learn will benefit all humankind.

A comparison of these statements shows that "air" or "aeronautics" has not been explicitly mentioned in the vision since 2000. Science has not been explicitly mentioned since 1986, when the vision mentioned aeronautics, space science, and exploration. The shortest of the visions, from 2003, succinctly encapsulates what NASA does, but, like the current one, does not explicitly mention aeronautics, science, or space, and is not easily identified as a NASA unique vision.

NASA mission statements have likewise evolved over time:

1994-2000: The NASA mission is to:

— Explore, use, and enable the development of space for human enterprise.

— Advance scientific knowledge and understanding of the Earth, the solar system, and the universe and use the environment of space for research.

— Research, develop, verify, and transfer advanced aeronautics, space, and related technologies.

2003: To understand and protect our home planet, to explore the universe and search for life, to inspire the next generation of explorers…as only NASA can.

2006: To pioneer the future in space exploration, scientific discovery, and aeronautics research.

2011: Drive advances in science, technology, and exploration to enhance knowledge, education, innovation, economic vitality, and stewardship of Earth.

These mission statements are longer and provide more detail than the vision statements, and they consistently mention NASA-related themes such as exploration and science. In addition, all of them explicitly mention aeronautics, except for two—the 2003 statement and the current (2011) formulations.

POLICY BACKGROUND

Despite NASA's broad portfolio that spans human spaceflight, space and Earth science, and aeronautics research, in the public mind the agency is most closely associated with human spaceflight. In 2004, after many years of uncertainty about the futures of the space shuttle and the ISS, President George W. Bush announced a "Vision for Space Exploration" that called for astronauts to return to the Moon by 2020 and someday to go to Mars. Similar goals had been expressed by President George H.W. Bush in 1989, but they did not receive bipartisan support, and the President's proposed budgets for achieving these goals were rejected. By 1992 the goals were essentially abandoned.

The 2004 Vision announcement followed by almost exactly a year the space shuttle *Columbia* tragedy that cost the lives of seven astronauts. The Columbia Accident Investigation Board noted in its report that if astronauts lives were to be at risk through space exploration, the rationale and goals needed to be better defined.

President George W. Bush did not propose adding significant funding to NASA's budget to accomplish the new goals, however. Instead, his plan was to terminate the space shuttle program in 2010 after completing construction of the ISS and to end U.S. involvement in the ISS in the 2015-2016 timeframe. The space shuttle and ISS funds would be redirected to achieving the Moon/Mars goals.

In 2005, a Republican-controlled Congress passed the 2005 NASA Authorization Act, which supported President Bush's Moon/Mars program while also stressing the need for adequate utilization of the ISS and holding open the possibility of continuing the space shuttle program beyond 2010. Three years later, a Democratic-controlled Congress passed the 2008 NASA Authorization Act that was similar to the 2005 act. At that point in time, Congress and the White House, Democrats and Republicans, were all in general agreement about the future of the human spaceflight program. NASA pursued the presidential and congressional policies by initiating the Constellation program to build capabilities to send people back to the Moon and to Mars, including new launch vehicles and spacecraft.

In January 2009, President Barack Obama convened a special committee to look at the human spaceflight program and offer options. Chaired by Norman Augustine, the committee concluded that there were "technical and budgetary issues" in major components of the Constellation program (e.g., Ares I, Orion) that were creating considerable schedule delays. Independent analyses showed that "the length of the gap in U.S. ability to launch astronauts into space [would] be at least seven years." The Augustine committee concluded further that in order for NASA to pursue a mission of sending humans beyond low Earth orbit (LEO), NASA required additional funding of $3 billion more per year.

In February 2010, as part of the fiscal year (FY) 2011 budget request, the White House proposed terminating the Constellation program and replacing it with a NASA effort to develop technologies for human exploration beyond LEO. No decision on what kind of vehicles to build would be made until at least 2015, and no specific destination or timeframe for human expeditions beyond LEO was included. Meanwhile, the President decided that instead of NASA developing a replacement capability for the space shuttle to ferry astronauts to and from the ISS, NASA would build on its Commercial Orbital Transportation Services (COTS) partnership agreements with U.S. industry, initiated in 2006. This approach would enable them to contract for the development of "commercial crew" space transportation systems, where NASA would help pay companies to develop their own space transportation systems, and the companies would invest significant amounts of their own money toward development with the expectation of the emergence of a private human spaceflight market.

Congress also wanted a destination and a timetable for sending astronauts beyond LEO. In April 2010, the President announced his goals of sending astronauts to an asteroid by 2025 and to orbit Mars in the 2030s. These goals were officially expressed in the 2010 National Space Policy issued by the White House two months later.

The totality of the decisions—to proceed with President Bush's plan to terminate the space shuttle, but to also end the Constellation program that was developing a replacement U.S. crew transportation capability—resulted in programmatic disruptions. These decisions also resulted in an indefinite extension of the number of years the United States would need to depend on Russia to take NASA astronauts to and from the ISS. In addition, the decisions to rely on the commercial sector to build a new U.S. crew space transportation system, when some were skeptical that the companies were technically ready to take on such a responsibility, and to replace the Moon with an unspecified asteroid as the next destination for human spaceflight—made without prior consultation and contravening two existing laws—were met with congressional skepticism.

A number of influential members of Congress insisted that the government—NASA—build a new crew transportation system regardless of any commercial crew aspirations. Congress wanted a new large rocket reminiscent of the Saturn V used for the Apollo program to enable trips beyond LEO, whatever the destination, and to accelerate as much as possible restoring U.S.' ability to launch people into space rather than relying on Russia.

In October 2010, Congress and the White House reached a compromise in the 2010 NASA Authorization Act. In essence, the agreement was for NASA to do both what the White House and Congress wanted. NASA would proceed with the White House plan for commercial crew transport as well as Congress's plan for a NASA-developed Space Launch System (SLS), based heavily upon legacy systems such as those developed for the space shuttle program, and an Orion spacecraft that would take humans beyond LEO and serve as a backup in case the commercial systems did not materialize.

The budget outlook for NASA, meanwhile, worsened. The President had planned to add $6 billion to NASA's budget over 5 years when he announced his new plan in the FY2011 budget request. A year later, with Republicans regaining control of the House and deficit-reduction becoming the dominant political theme, NASA was hoping for level funding at best. Today, the same NASA that was deemed by the Augustine committee to be unable to afford the Constellation program now must fund Constellation's replacement—SLS/Orion—and also fund commercial crew transport. NASA still must find funds for a habitation and support module to enable long duration trips beyond LEO.

Some in Congress remain wary of the administration's plans, stating that budget requests since the 2010 NASA Authorization Act have favored spending on commercial crew rather than SLS/Orion. NASA also took longer than expected to choose an SLS design, prompting congressional criticism that the agency was delaying making a decision. All the while, support for the idea of sending astronauts to an asteroid failed to gain widespread support, and NASA has not undertaken any visible steps required to make such a mission possible. These issues, in part, led Congress to commission the current study to examine NASA's strategic direction.

The one piece of common ground is that sending humans to Mars remains the long-term goal for everyone involved in this debate. As shown in Box 1.1, that has been the driving force in presidential policies and speeches for decades. The debate is about the steps between the ISS and Mars and when we will get there, dictated largely by budget constraints.

BOX 1.1
The Presidents Speak on Human Exploration of Mars

President George H.W. Bush
Address at the National Air and Space Museum
July 20, 1989

In 1961 it took a crisis—the space race—to speed things up. Today we don't have a crisis; we have an opportunity. To seize this opportunity, I'm not proposing a 10-year plan like Apollo; I'm proposing a long-range, continuing commitment. First, for the coming decade, for the 1990′s: Space Station Freedom, our critical next step in all our space endeavors. And next, for the new century: Back to the Moon; back to the future. And this time, back to stay. And then a journey into tomorrow, a journey to another planet: a manned mission to Mars (Bush, 1989).

President George W. Bush
Remarks on U.S. Space Policy at NASA Headquarters
January 14, 2004

With the experience and knowledge gained on the moon, we will then be ready to take the next steps of space exploration: human missions to Mars and to worlds beyond. Robotic missions will serve as trailblazers—the advanced guard to the unknown. Probes, landers and other vehicles of this kind continue to prove their worth, sending spectacular images and vast amounts of data back to Earth. Yet the human thirst for knowledge ultimately cannot be satisfied by even the most vivid pictures, or the most detailed measurements. We need to see and examine and touch for ourselves. And only human beings are capable of adapting to the inevitable uncertainties posed by space travel (Bush, 2004).

President Barack Obama
Speech Outlining his Administration's Space Policy at Cape Canaveral, Florida
April 15, 2010

By 2025 we expect new spacecraft designed for long journeys to allow us to begin the first ever crewed missions beyond the Moon into deep space. So we'll start by sending astronauts to an asteroid for the first time in history. By the mid-2030s I believe we can send humans to orbit Mars and return them safely to Earth. And a landing on Mars will follow and I expect to be around to see it (Siceloff, 2010).

2011 NASA STRATEGIC PLAN

Office of Management and Budget (OMB) Circular A-11 (section 230) requires federal agencies to prepare strategic plans that define long-term objectives and to explain why those objectives were selected, how they will be achieved, and how progress will be measured. Strategic plans are expected to include appraisals of agency capabilities and provide a context for making decisions about agency priorities and budgets.

The most recent NASA strategic plan was issued in 2011 (NASA, 2011). Overall, the 2011 strategic plan is generally consistent with the 2010 National Space Policy, although there are some differences in emphasis. The 2011 strategic plan describes six strategic goals, each of which is associated with two to five desired outcomes. (See Box 1.2, which also lists the challenges identified for each strategic goal.[1]) The six strategic goals are aligned with eight of NASA's nine major budget line items for FY2012. In other words, the strategic plan does not identify any strategic goals that are not already funded in NASA's current budget. Importantly, however, the strategic plan does not address the rationale

[1] More information on all of the goals, objectives, and challenges is included in the strategic plan (NASA, 2011).

for resource allocation among the six strategic goals. In addition, while the NASA budget does not provide a breakdown of budget estimates associated with of the six strategic goals, it appears that the first two goals—human spaceflight and space science—account the for the large majority of the NASA budget, while two other goals—aeronautics and technology development—receive, in total, only 6.4 percent of the budget. The 3.2 percent for aeronautics is a surprisingly small investment considering its importance to the U.S. economy and world leadership position. It is apparent, however, that some of the outcomes and challenges presented in the 2011 strategic plan will not be achieved by NASA as its programs are currently structured and funded because NASA does not have the resources needed or because of shortcomings in the state of the art of related science and/or technology.

The 2006 NASA strategic plan had similarly broad goals to those in the 2011 plan, but with somewhat greater specificity, e.g., its first strategic goal is to "fly the shuttle as safely as possible until its retirement, not later than 2010." (See Figure 1.2.) Consistent with the initiation of the COTS program in 2006, there is a strategic goal to "Encourage the pursuit of appropriate partnerships with the emerging commercial space sector." The 2003 NASA strategic plan that was created earlier in the Bush Administration is much more similar to the current NASA plan in that there are broad, sweeping goals with relatively little specificity. Neither the 2003 plan nor the 2006 plan explicitly lists any prioritization in their strategic goals.

FIGURE 1.2 The space shuttle *Endeavour,* atop the Shuttle Carrier Aircraft lands at Los Angeles International Airport on September 21, 2012, in Los Angeles, California. SOURCE: NASA/Matt Hedges.

BOX 1.2
NASA's 2011 Strategic Goals, Outcomes, and Challenges

Strategic Goal 1: Extend and sustain human activities across the solar system.

Outcomes

1.1 Sustain the operation and full use of the International Space Station (ISS) and expand efforts to utilize the ISS as a National Laboratory for scientific, technological, diplomatic, and educational purposes and for supporting future objectives in human space exploration.
1.2 Develop competitive opportunities for the commercial community to provide best value products and services to low Earth orbit and beyond.
1.3 Develop an integrated architecture and capabilities for safe crewed and cargo missions beyond low Earth orbit.

Challenges

Advanced Technology Development
Availability of Commercial Cargo and Crew Services
Affordability and Sustainability

Strategic Goal 2: Expand scientific understanding of the Earth and the universe in which we live.

Outcomes

2.1 Advance Earth system science to meet the challenges of climate and environmental change.
2.2 Understand the Sun and its interactions with Earth and the solar system.
2.3 Ascertain the content, origin, and evolution of the solar system and the potential for life elsewhere.
2.4 Discover how the universe works, explore how it began and evolved, and search for Earth-like planets.

Challenges

Access to Space
Program Management
Availability of Plutonium 238

Strategic Goal 3: Create the innovative new space technologies for our exploration, science, and economic future.

Outcomes

3.1 Sponsor early-stage innovation in space technologies in order to improve the future capabilities of NASA, other government agencies, and the aerospace industry.
3.2 Infuse game-changing and crosscutting technologies throughout the Nation's space enterprise to transform the Nation's space mission capabilities.
3.3 Develop and demonstrate the critical technologies that will make NASA's exploration, science, and discovery missions more affordable and more capable.
3.4 Facilitate the transfer of NASA technology and engage in partnerships with other government agencies, industry, and international entities to generate U.S. commercial activity and other public benefits.

Challenge

Implementation of a New Approach.

continues

BOX 1.2 (continued)

Strategic Goal 4: Advance aeronautics research for societal benefit.

Outcomes

4.1 Develop innovative solutions and advanced technologies through a balanced research portfolio to improve current and future air transportation.
4.2 Conduct systems-level research on innovative and promising aeronautics concepts and technologies to demonstrate integrated capabilities and benefits in a relevant flight and/or ground environment.

Challenges

Inherent Risk
Partnership Influences
Resources

Strategic Goal 5: Enable program and institutional capabilities to conduct NASA's aeronautics and space activities.

Outcomes

5.1 Identify, cultivate, and sustain a diverse workforce and inclusive work environment that is needed to conduct NASA missions.
5.2 Ensure vital assets are ready, available, and appropriately sized to conduct NASA's missions.
5.3 Ensure the availability to the Nation of NASA-owned, strategically important test capabilities.
5.4 Implement and provide space communications and launch capabilities responsive to existing and future science and space exploration missions.
5.5 Establish partnerships, including innovative arrangements, with commercial, international, and other government entities to maximize mission success.

Challenges

Meeting Changing Facilities Requirements
Achieving and Sustaining State-of-the-Art Technologies for Institutional Capabilities
Managing a Distributed Infrastructure Base

Strategic Goal 6: Share NASA with the public, educators, and students to provide opportunities to participate in our Mission, foster innovation, and contribute to a strong national economy.

Outcomes

6.1 Improve retention of students in STEM disciplines by providing opportunities and activities along the full length of the education pipeline.
6.2 Promote STEM literacy through strategic partnerships with formal and informal organizations.
6.3 Engage the public in NASA's missions by providing new pathways for participation.
6.4 Inform, engage, and inspire the public by sharing NASA's missions, challenges, and results.

Challenges

Attracting Students to Science, Technology, Engineering, and Mathematics
Reaching New Audiences

SOURCE: NASA (2011).

NASA ORGANIZATION AND STAFF LEVELS

NASA's organization includes nine field centers: Ames Research Center, Dryden Flight Research Center, Glenn Research Center, Goddard Space Flight Center, Johnson Space Center, Kennedy Space Center, Langley Research Center, Marshall Space Flight Center, and Stennis Space Center. The Jet Propulsion Laboratory (JPL) is not a NASA field center, but is instead a federally funded research and development center (FFRDC), although it is commonly referred to as a NASA field center. NASA also operates several other facilities such as the Wallops Flight Facility, which is managed by Goddard Space Flight Center and used as a launch site for small satellites, sounding rockets and some air vehicles. NASA also operates the Michoud Assembly Facility, which is managed by Marshall Space Flight Center and has the ability to manufacture and test large scale rocket engines and their components.

The location of the centers is shown in Figure 1.3. NASA, like many government agencies, augments its civil servant workforce with contractors, both for direct support and to provide the equipment and capabilities that the agency procures, such as launch vehicles and spacecraft.

All of the NASA centers have long and varied histories; the oldest, Langley Research Center, will celebrate its centennial in 2017. The capabilities of some centers overlap, to some degree, with other centers, but differences in staff expertise, facility capabilities, history, mission, culture, and current issues and challenges make it difficult to address some management issues with a one-size-fits-all approach.[2]

On-site contractors play a major role at all the NASA centers. As shown in Table 1.1, the size of the contractor workforce exceeds the size of the civil servant workforce at each of the centers. The numbers of civil servants and contractors are roughly comparable at half of the centers (Ames Research Center, Dryden Flight Research Center, Glenn Research Center, Langley Research Center, and Marshall Space Flight Center). The number of on-site contractors far exceeds the number of civil servants at the other centers (Goddard Space Flight Center, Johnson Space Center, Kennedy Space Center, and Stennis Space Center). Overall, about one-third of the staff working at NASA centers are civil servants and about two-thirds are on-site contractors.

Virtually all of JPL's workforce is composed of contractors who are employed by the California Institute of Technology, which operates JPL, although about 300 NASA civil servants are assigned there. Stennis Space Center, which is focused on ground-based rocket testing, encompasses 140,000 acres, has a relatively small civil service staff, and most of the rest of the staff are contractors.

Since FY2000, the total size the civil servant workforce (which includes full-time, part-time permanent, term appointment, student, and other non-permanent staff) has been relatively stable, with an average of 18,272 staff, with a maximum of 18,633 and a minimum of 17,219 (NASA, 2012).

At NASA headquarters, primary program activities are carried out by the Human Exploration and Operations Mission Directorate (HEOMD), the Science Mission Directorate, the Aeronautics Research Mission Directorate, and the Office of the Chief Technologist. More information on these activities appears below in the section "NASA's Primary Program Areas."

Figure 1.4 shows the historical trend in NASA budget outlays (adjusted to constant FY2011 dollars).[3] In the post-Apollo era, NASA spending was relatively flat throughout the remainder of the 1970s and first half of the 1980s. Outlays increased significantly the late 1980s, which was a period of rapid expansion of the ISS program in concert with robust space shuttle and space science programs. Starting in 1987, NASA's budget increased to cope with the aftermath of the *Challenger* accident. The DOD was directed to transfer $2.1 billion to NASA in FY1987 as a lump sum to pay for a replacement

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[2] Conclusions and recommendations related to the issues faced by the centers are provided in the Chapter 2 section, "Examining NASA's Institutional Structure."

[3] For agencies with stable budgets, outlays in any given fiscal year tend to approximate the annual budgets for those agencies as approved by the appropriations act or other federal legislation (such as a continuing resolution) for those agencies. Differences arise between annual outlays and budgets because funding provided in one year's budget is not completely expended before the end of the fiscal year.

orbiter, and NASA was allocated other return-to-flight funding. This money was to cope with programmatic delays for spacecraft that had to be launched on the space shuttle (like the Hubble Space Telescope and Galileo), and funds to change to a "mixed fleet" approach where the agency would procure expendable launch vehicle services for spacecraft previously scheduled for launch on the space shuttle. NASA's budget, therefore, rose steadily from FY1987 to FY1991, but stabilized thereafter. NASA spending reached a plateau in the early 1990s and has remained within a relatively small band for a period of almost two decades since the mid-1990s.

TABLE 1.1 NASA Civil Service and Contractor Personnel by Field Center (including the Jet Propulsion Laboratory), Fiscal Year 2012[a]

NASA Center	Number of Civil Servants (Full-Time Permanent)[b]	Number of Contractors[c]	Total Number of Employees	Percentage of Civil Servants	Percentage of Contractors
Ames Research Center	1,243	1,322	2,565	48%	52%
Dryden Flight Research Center	576	650	1,226	47%	53%
Glenn Research Center	1,710	1,690	3,400	50%	50%
Goddard Space Flight Center	3,428	6,100	9,528	36%	64%
Jet Propulsion Laboratory	~ 300[c]	4,848	~5,150	~6%	~94%
Johnson Space Center	3,383	~12,000	~15,400	75%	25%
Kennedy Space Center	2,178	6,099	8,277	~25%	~75%
Langley Research Center	1,938	1,700	3,638	53%	47%
Marshall Space Flight Center	2,563	3,537	6,100	42%	58%
Stennis Space Center	294	~2,000[d]	~2,300	~13%	~87%
Total	17,613	~40,000	~57,500	~31%	~69%

NOTE: Does not include Headquarters personnel.

[a] During its visits to the NASA field centers the committee enquired about the aging of the NASA workforce and was informed that this is no longer considered a concern by the field center leadership. Over the past several years, NASA has engaged in a selective hiring program that has brought in new, and younger employees, generally reversing an aging workforce trend that had been highlighted as a problem by previous NASA leadership.

[b] NASA, 2012.

[c] Information provided to committee members by center staff during site visits by small groups of committee members to each NASA center.

[d] NASA's Stennis Space Center manages a site that includes a total of approximately 5,200 personnel, including, many civil service and contractors from other government agencies and industry who are funded by organizations other than NASA for their own purposes. About 2,000 of them are working under contract to NASA.

FIGURE 1.3 NASA Headquarters, the NASA centers, and the Jet Propulsion Laboratory. SOURCE: NASA.

Many NASA observers have cited the relationship of NASA spending to gross domestic product or to the federal budget total as a proxy measure of the national priority assigned to NASA. Due to the changes in federal budget policy over the past 25 years, a more reasonable benchmark is to compare NASA outlays to total federal non-defense discretionary spending, i.e., the portion of the budget that is annually appropriated by Congress, of which NASA is a part. Using this measure, Figure 1.5 shows that NASA outlays constituted about 4 percent of non-defense discretionary spending in the post-Apollo era in the 1970s and early 1980s, rising to 6 percent with the NASA budget build-up in the late 1980s and early 1990s, and then gradually declining to a level of about 3 percent of non-defense discretionary spending. This is not to imply that there should be any specific target benchmark for the NASA budget, but rather to point out that, particularly in recent years, the NASA budget has been remarkably constant in both absolute spending levels as well as share of non-defense discretionary spending for at least a decade. This trend, reflecting the series of decisions on the NASA budget by the administration and Congress each year, provides important context for the discussion of issues related to NASA's strategic direction in Chapter 2.

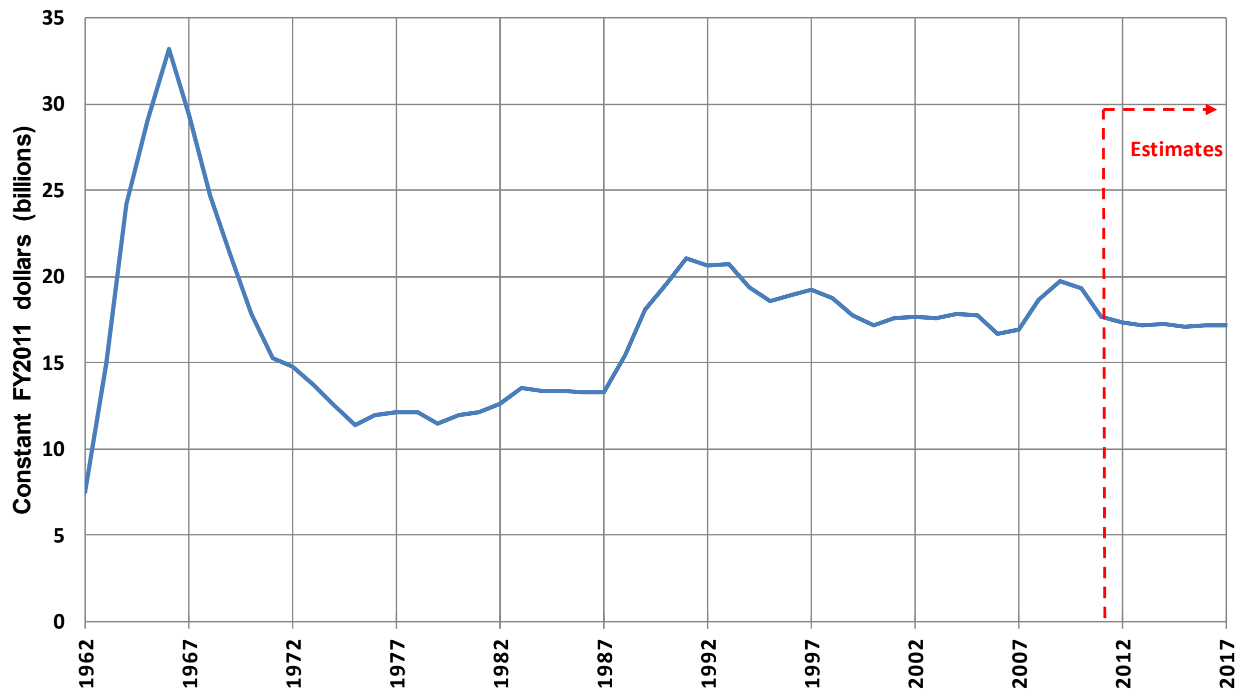

FIGURE 1.4 NASA outlays in constant fiscal year (FY) 2011 dollars (billions), FY1962 to FY2017. NASA's first budget was FY1959, but comparable OMB data for FY1959-FY1961 are not available. SOURCE: NRC, based on data from OMB (2012) and adjusted for inflation by the NRC using the GDP Chained Price Deflator in OMB (2012, Table 4.1, Outlays by Agency: 1962-2017 and Table 10.1, Gross Domestic Product and Deflators Used in the Historical Tables: 1940-2017, Column 3, GDP (Chained) Price).

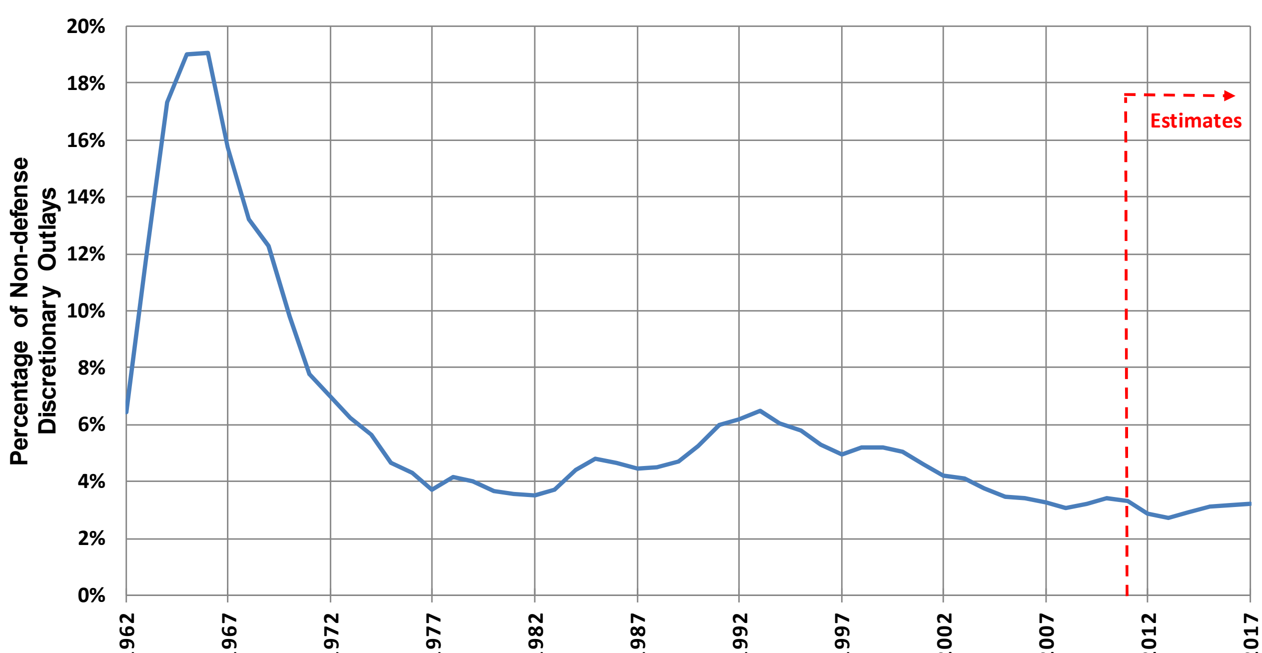

FIGURE 1.5 NASA outlays as a percentage of non-defense discretionary outlays, fiscal year (FY) 1962 to FY2017. SOURCE: NRC, based on data from OMB (2012, Table 8.1, Outlays by Budget Enforcement Act Category: 1962-2017).

NASA'S PRIMARY PROGRAM AREAS

Human Exploration and Space Operations

Currently, NASA is developing a Space Launch System program, the goal of which is to create a heavy-launch vehicle capable of transporting humans and cargo, including the Orion Multi-Purpose Crew Vehicle, beyond LEO (see Figure 1.6 and 1.7). The first SLS launch is slated for 2017 carrying a prototype Orion capsule without a crew.[4] These two projects account for about 80 percent of the exploration budget. The balance of the budget supports commercial spaceflight activities and research and development of various exploration systems.

Space operations remains a separate line item, at least for now. It pays for the cost of operating and maintaining the ISS as well as communications, launch services, and a few other items in the Space Flight and Support line. It includes closing out the Space Shuttle Program. NASA has recently merged the two organizations at NASA headquarters that managed these programs to form the Human Exploration and Operations Mission Directorate. Most NASA centers receive funding from HEOMD to some degree; the leaders include Johnson Space Center, Kennedy Space Center, Marshall Space Flight Center, Glenn Research Center, and Langley Research Center. Human exploration and space operations together account for almost half of NASA's FY2012 budget. [5] NASA also performs life and microgravity science research funded by HEOMD. This research, among other things, is intended to determine how the human body adapts to long-duration spaceflight and how to mitigate the negative effects of microgravity and other issues.

FIGURE 1.6 The Space Launch System, is being designed to carry the Orion Multi-Purpose Crew Vehicle. SOURCE: NASA.

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[4] See http://www.nasa.gov/pdf/664158main_sls_fs_master.pdf. Accessed October 2012.

[5] At the time that this study was concluding, the NRC was starting a new study on the goals of the human spaceflight program.

FIGURE 1.7 Water impact test of an 18,000-pound (8,165 kilogram) test version of the Orion spacecraft at NASA's Langley Research Center on August 23, 2012. SOURCE: NASA.

Earth and Space Science

Earth and space science is primarily concerned with scientific inquiries associated with Earth, the Sun and its sphere of influence (heliophysics), bodies in the solar system other than Earth or the Sun (planetary science), and the expanse of the universe outside the solar system. Although these are collectively managed by NASA's Science Mission Directorate, they each face somewhat different challenges, have different constituencies and politics, and fulfill different needs. Each of these topics is addressed briefly below. Additional information is available in the following most recent decadal surveys published on these topics by the NRC:

Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond (NRC, 2007);
Solar and Space Physics: A Science for a Technological Society [prepublication version] (NRC, 2012b);
Vision and Voyages for Planetary Science in the Decade 2013-2022 (NRC, 2011); and
New Worlds, New Horizons in Astronomy and Astrophysics (NRC, 2010).

These decadal surveys (as well as a decadal survey in life and microgravity science produced in 2011) are a primary source of strategic guidance for NASA science programs. In some cases, there is generally a good correlation between the strategic plans and the priorities that NASA establishes for the space sciences. Counterexamples include (1) NASA's recent decision to postpone indefinitely work towards a Mars sample return mission, even though a Mars sample return mission is the highest priority in the most recent decadal survey for planetary science (NRC, 2011) and (2) substantial and unexpected reductions in the budget for astrophysics that make it impossible for NASA to develop the highest-priority missions in the most recent decadal survey for astronomy astrophysics until late this decade (NRC, 2010).

Earth Science

Earth is a complex, ever-changing system that directly affects national and global prospects for sustainable prosperity and well being. NASA is currently completing the development of a set of foundational missions, decadal survey missions, and climate continuity missions. Integrated investigations of Earth's interior, land surface, biosphere, atmosphere, and oceans are essential to understand and predict changes to Earth and the impact that those changes will have on humanity in terms of climate variability and change, land-use changes, biodiversity, oceanography, water resources and the global hydrologic cycle, atmospheric chemistry, and weather. Understanding these changes will, in some cases, inform national and international policy decisions intended to accommodate and/or mitigate specific changes. With regard to accurately understanding Earth's systems, NASA has the lead in making and interpreting most Earth science observations from space and has partnered with the National Oceanic and Atmospheric Administration (NOAA), which has the lead for weather observations and prediction (NRC, 2007).

Heliophysics

Some issues of particular importance to heliophysics (that is, solar and space physics) are relevant to life on Earth. These issues include the ability to predict variations in the space environment caused by the Sun and understanding the response of Earth's magnetosphere, ionosphere, and atmosphere to variations in solar-terrestrial conditions. Heliophysics also examines how the Sun interacts with other bodies within the solar system. The recent decadal survey report on solar and space physics outlined four scientific goals going forward and recommended continued support for the program elements of a heliosphysics systems observatory and to implement programs in advanced stages of development. This includes the Radiation Belt Storm Probes that were recently launched to understand the Sun's influence on Earth by studying Earth's radiation belts. Advances in heliophysics require scientists to study the Sun, Earth, and the heliosphere[6] as a coupled system, and NASA has the knowledge and spacecraft to do just that (NRC, 2012b).

Planetary Science

Areas of particular interest include understanding the origin and evolution of terrestrial planets and detailing the processes that drive climate on Earth-like planets. But the science goals of planetary missions vary widely depending on the destination(s) of a particular mission and the instruments that it carries. Climate processes are of interest in the study of Mars, as is the quest to determine (1) if life has ever existed on Mars and (2) how conditions on the surface of the planet and in the interior have evolved over time. The recently-landed NASA/JPL Mars Curiosity Rover, shown in Figure 1.8, is an example of robotic exploration to answer such questions. Distinct sets of science goals also exist for the other planets, for planetary moons, and for other objects in the solar system (NRC, 2011). Planetary science was subject to significant budget cuts in the President's FY2013 budget, forcing NASA to drop out of a partnership with the European Space Agency (ESA)-led ExoMars missions. The Mars Program Planning Group, which was chartered to provide options for a Mars mission that integrate science, human exploration, and technology, recently recommended several avenues for a sample return mission from Mars. This recommendation closely aligns with that of the NRC decadal survey for planetary science. However, Mars sample return has not yet been adopted by the administration as a priority goal for NASA.

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[6] The heliosphere is the region of space subject to the effects of the solar wind, which consists of charged particles (mostly electrons and protons) emitted by the Sun.

Although Mars has received a great deal of attention in the past year, the reality is that NASA's planetary science program has a tremendous number of spacecraft currently in operation. The Cassini mission is still healthy and returning a wealth of data on Saturn. NASA currently operates the Lunar Reconnaissance Orbiter as well as the dual spacecraft Ebb and Flow around the Moon. The MESSENGER spacecraft is the first ever to orbit Mercury. New Horizons is heading toward a 2015 rendezvous with Pluto, and Juno will orbit Jupiter that same year. Mars Reconnaissance Orbiter and Mars Odyssey, as well as the Opportunity rover all continue operating at Mars. At the time this report was being prepared, the Dawn spacecraft had left the asteroid Vesta en route to the large asteroid Ceres. Collectively, these missions have provided substantial amounts of information on our solar system, and they are rewriting our current understanding of the formation and evolution of the solar system, contributing to the search for the existence of past or even current life on other planets and assisting in the understanding of exoplanets.

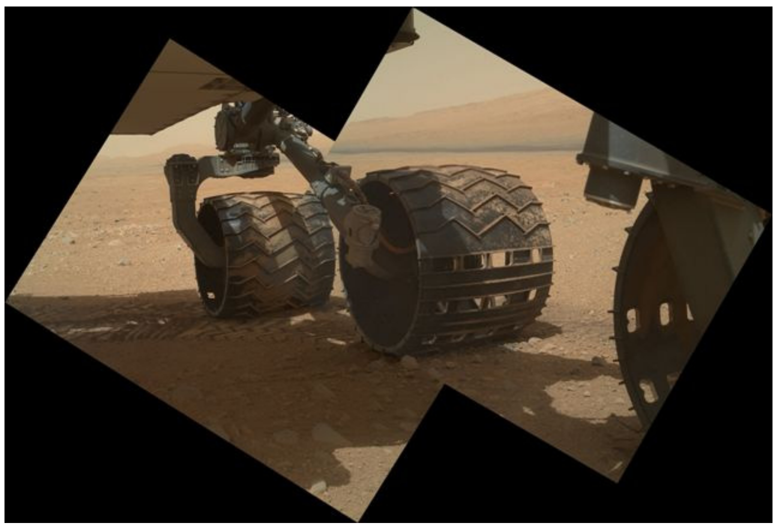

FIGURE 1.8 This view of the three left wheels of NASA's Mars rover Curiosity combines two images that were taken by the rover's Mars Hand Lens Imager during the 34th martian day, or sol, of Curiosity's work on Mars (September 9, 2012). In the distance is the lower slope of Mount Sharp. SOURCE: NASA/JPL.

Astronomy and Astrophysics

NASA astrophysics missions allow the modern scientific explorers to search over unimaginable distances: the closest star (other than the Sun) is more than 20 trillion miles away, and the distance to the closest galaxy (other than our home galaxy) is thousands of times farther away. Astronomical instruments look across space and back in time: the Hubble Space Telescope, which can make observations free of the distorting effects of Earth's atmosphere, has observed the most distant object seen, more than 13 billion light-years away, just as it appeared 13 billion years ago. The Hubble Space Telescope, the James Webb Space Telescope (shown in Figure 1.9 and scheduled for launch in 2018), and other current and future missions will allow scientists to continue to explore in greater depth the most basic questions of human destiny. However, current budget priorities of the administration have led to delays—probably to the end of the decade—before a new program could be developed to pursue the most recent decadal survey priority in dark energy science, exoplanet science, and an understanding of the cosmos.

FIGURE 1.9 Technicians and scientists check out one of the James Webb Space Telescope's first two flight mirrors on September 19, 2012, in the clean room at NASA's Goddard Space Flight Center in Greenbelt, Maryland. SOURCE: NASA.

Aeronautics

Aeronautics research is the foundation on which NASA was built, having been created out of the aeronautics research facilities of the National Advisory Committee for Aeronautics.[7] Four of the ten NASA centers were founded as part of these NACA facilities, and although a number of legacy facilities such as large subsonic wind tunnels have been "mothballed" or even dismantled over the years, many of the NASA aeronautics facilities are utilized regularly by other government agencies such as DOD, the Federal Aviation Administration (FAA), and NOAA. The federal government's longstanding interest in aeronautics research is justified by the direct and indirect impacts that aeronautics has on the U.S. economy through the development of safe, efficient civil and military air vehicles. NASA aeronautics research has included focused investigations in many different disciplines (e.g., aerodynamics, propulsion, materials and structures, avionics, and flight dynamics and controls) directed at many different applications (e.g., efficient subsonic fixed-wing aircraft, high-speed civil transport systems, rotary wing aircraft, and even hypersonic airbreathing engines for multiple-stage-to-orbit space access). During the past 6 years, the key priorities and goals for NASA aeronautics research have included increased aviation system capacity, improved aircraft safety and reliability, increased vehicle efficiency and performance, reduced energy consumption and environmental impact, utilizing the synergies with national defense and homeland security, and support for the space program. An example of NASA research aircraft for developing new fuel efficiency technologies is shown in Figure 1.10.

[7] NASA's Langley Research Center, Ames Research Center, Glenn Research Center, and Dryden Flight Research Center trace their roots to NACA's Langley Memorial Aeronautical Laboratory (Hampton, Virginia), Ames Aeronautical Laboratory (Moffett Field, California), Aircraft Engine Research Laboratory (Cleveland, Ohio), and Muroc Flight Test Unit (Edwards Air Force Base, California), respectively.

FIGURE 1.10 The NASA X-48C, which is a remotely piloted model of a hybrid wing body aircraft, takes flight for the first time. This aircraft is used for developing new fuel efficiency technologies. SOURCE: NASA/Tony Landis.

Space Technology

Because of the unique nature of most NASA missions, NASA has had a number of very specific technological requirements in areas ranging from expendable and reusable launch vehicles to deep space propulsion systems, and much more. As a consequence NASA has invested heavily in the development of advanced space technology over the years. Technological advances in these areas have yielded benefits far beyond space exploration itself in down-to-Earth applications (NASA, 2008).

In the early decades of NASA's existence, the accelerated development of concepts such as rockets and sensing technologies were given sufficient resources to meet ambitious timetables, e.g., the Saturn V development for the Apollo program or the Space Shuttle Main Engine development for the space shuttle. Since then, concepts for NASA space transportation in particular tended to be technologically ambitious (e.g., the X-33) and/or significantly constrained by the budget (e.g., Constellation). Guidance on specific mission-related development of space technologies, apart from launch systems, now routinely appears in the decadal surveys produced by the NRC for Earth and space science (see NRC, 2010, 2011, and 2012b).

In the past decade, until recently, an explicit line item for space technology, apart from launch technology, was absent from the NASA budget. In the FY2012 budget, the Space Technology Program was established, in part with funds freed up by cancellation of Constellation. The Space Technology Program, which is managed by NASA's Office of the Chief Technologist, is intended to complement technology development conducted by NASA's mission directorates. The Space Technology Program will focus on crosscutting technologies that serve the needs of multiple NASA mission directorates, government agencies, and industries; an example is shown in Figure 1.11. The Space Technology Program will also support technologies that would enable unprecedented new missions or capabilities but are too risky to warrant substantial investment by the mission directorates. Guidance on mission-related development of space technologies now routinely appears in the decadal surveys produced by the NRC for Earth and space science (see NRC, 2010, 2011, and 2012b). Most recently the NRC completed a major roadmapping study that established technology development goals for the Space Technology Program, and NASA has now begun implementing those goals into its plans (NRC, 2012). Congress directed that one-third of the Space Technology Program's current budget be dedicated to research focused on human exploration goals (U.S. House of Representatives, 2011).

FIGURE 1.11 Robonaut 2 during checkout on the International Space Station. SOURCE: NASA.

Cross-Agency Support

Since 2008, Cross Agency Support has been used to fund a range of NASA operations in these areas, including the construction of facilities and infrastructure, to provide capabilities that cannot be tied directly to the specific needs of a particular directorate or program. Cross Agency Support also funds center management and operations and agency management and operations and is a vital part of NASA operations.

NASA-SUPPORTED COMMERCIAL SPACE ACTIVITIES

Since the late 1950s, the U.S. government has been involved extensively in setting requirements, designing, testing, developing, and launching human and robotic spacecraft. NASA's Commercial Orbital Transportation Services program, initiated in 2006, is designed to foster development of privately operated space transportation systems for access to the ISS. This program, which is currently in Phase 2, is a public-private partnership, in that both NASA and the participating contractors contribute to the cost of developing new systems. Currently, both SpaceX and Orbital Sciences Corporation are under contract to develop new launch vehicles and spacecraft, and on May 25, 2012 and again on October 9, 2012, a Dragon capsule (without a crew) successfully berthed with the ISS. (See Figure 1.12.) In addition, some private companies, such as Virgin Galactic, are developing relatively low-cost, suborbital space transportation systems on their own, with the expectation that space tourism by individuals will become a viable business model. To date, more than 500 individuals have made deposits of $20,000 to $200,000 with Virgin Galactic toward a future flight on a Virgin Galactic spacecraft (still under development). Now that NASA has adopted an initiative to develop commercial capabilities with private companies who are entering the business of developing testing and operating space systems, the government no longer has an *exclusive* role in the design, development, testing, evaluation, and operations role for human spacecraft systems.

NASA's new approach to procuring transportation services is an extension of U.S. government policy that discourages direct government competition with industry in manufacturing systems or providing services that are available in the private marketplace. Of course, this approach is possible only because of previous investments by NASA and DOD over many decades in the development of launch vehicles, systems, processes, technologies, and components. Just as many ongoing improvements in commercial spacecraft are enabled by NASA's ongoing development of advanced technologies for future civil space missions, the growth of a U.S. commercial space transportation sector would be greatly facilitated by continued investments by NASA in space transportation technology. 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. Also, as a major consumer of space transportation services, it is in NASA's interest to promote advances in space transportation technologies, systems, and capabilities. NASA research is particularly important for precompetitive technologies that are at such a low level of maturity and/or have such a high level of risk that industry cannot justify developing these technologies using private capital.

FIGURE 1.12 The SpaceX Dragon commercial cargo craft approaches the International Space Station on May 25, 2012, for grapple and berthing. SOURCE: NASA.

SUMMARY

During the first 6 years of its existence, NASA's budget increased by an average of 70 percent each year. With the race to the Moon in full swing, NASA's budget topped out at $37 billion (in FY2011 dollars) in 1965. After falling by 60 percent after the end of the Apollo program, the budget topped out again at $23 billion in FY1991 to support a high level of activity on both the space shuttle and ISS programs. More recently, NASA's budget has been relatively stable. During the 15-year period from 1997 through 2011, the budget each year has varied by no more than 5 percent from the average value of $18.4 billion (in FY2011 dollars).

Despite the relative stability of NASA's budget and workforce over the last 15 years, NASA is going through a profound transition:

From a period of robust space exploration and operations with well-defined and supported objectives to one where there is a clear long-term destination for human exploration (Mars) but a lack of a well-defined national initiative or consensus on the path to get there.

From a period when the United States had space transportation capabilities second-to-none to a period where we must rely on others to launch our astronauts.

At a time when U.S. leadership in space science is being threatened by insufficient budgets to carry out the missions identified in the strategic plans (decadal surveys) of the science communities, the cost of missions is rising, science budgets are decreasing, and partnerships with the ESA are collapsing—even as other space agencies (most notably ESA) are mounting increasingly ambitious programs.

From a period where the primary focus of four NASA field centers was on aeronautics research and technology development and where NASA contributed major advances in these areas to the benefit of the U.S. economy, quality of life, and national security, to a period where the continued viability of those centers requires financial support from NASA programs or outside organizations other than NASA's aeronautics program.

At a time when the strategic importance of space is rising and the capabilities of other spacefaring nations are increasing, while U.S. leadership is faltering.

The factors that are driving these transitions and possible corrective action are addressed in Chapter 2.

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2
Findings, Conclusions, and Recommendations

THE NASA STRATEGIC PLAN AND STRATEGIC DIRECTION

The Committee on NASA's Strategic Direction was tasked to assess whether NASA's strategic direction, as defined by the *2011 NASA Strategic Plan* (described in Chapter 1), remains viable and whether the agency's activities and organization efficiently and effectively support that direction in light of the potential for constrained budgets for the foreseeable future. The 2011 strategic plan is tied (as required by law) to NASA's current budget. Whereas the Government Performance and Results Act was intended to require federal departments and agencies to state their priorities in their published strategic plans, the *2011 NASA Strategic Plan* is vague and avoids stating priorities. While the 2003 and 2006 NASA strategic plans were similarly lacking in prioritization, the current fiscally challenged era requires much clearer justification and prioritization for the plan to be meaningful. The 2011 strategic plan contains vision and mission statements as well as six strategic goals, as described in Chapter 1. While there are clear linkages between current NASA programs and the goals, there is no explicit prioritization among the goals in the 2011 strategic plan. For instance, there is no clear linkage between the details in the plan and the space exploration goals and priorities established by the administration in terms of sending astronauts to an asteroid as an interim destination before sending humans to orbit and eventually to land on Mars. In turn, the definition of these goals also contributes to the lack of clarity in strategic direction. For example, Strategic Goal 2 combines Earth science and space science and thus does not set a clear strategic objective for either one, nor does it establish or discuss priorities among the two areas. In addition, Strategic Goal 3 (create innovative new space technologies), Strategic Goal 5 (enable program and institutional capabilities to conduct NASA's aeronautic and space activities), and Strategic Goal 6 (share NASA with the public, educators, and students to provide opportunities to participate in NASA's mission, foster innovation, and contribute to a strong national economy) are not necessarily goals unto themselves, but rather are elements in an enabling strategy to accomplishing goals 1, 2, and 4.

> **Finding:** The **vision statement** for NASA in the *2011 NASA Strategic Plan*—to reach for new heights and reveal the unknown, so that what we do and learn will benefit all humankind—does not articulate a national vision that is unique to the nation's space and aeronautics agency.
>
> **Finding:** The **mission statement** for NASA in the *2011 NASA Strategic Plan*—drive advances in science, technology, and exploration to enhance knowledge, education, innovation, economic vitality, and stewardship of Earth—does not articulate a mission unique to the nation's space and aeronautics agency.
>
> **Finding:** Both the NASA vision and mission statements are generic statements that could apply to almost any government research and development (R&D) agency, omitting even the words "aeronautics" or "space." NASA's current vision and mission statements do not explain NASA's unique role in the government and why it is worthy of taxpayer investment. The non-specificity

of the vision and mission statements is a contributing factor to the confusion about NASA's overall strategic direction.

Conclusion: The *2011 NASA Strategic Plan* (like some prior NASA strategic plans) is vague and avoids stating any clear prioritization of the goals described therein. In addition, the document is broad in scope and vague on details and does not have a clearly defined plan about how to achieve the agency's goals and objectives. Consequently, the strategic plan, as formulated, does not provide sufficient strategic clarity or the guidance that NASA will require as the agency deals with the technical, programmatic, and budgetary challenges that are likely in the next 10 to 50 years.

The above troubling aspects of the *2011 NASA Strategic Plan* render it of little value from the perspective of establishing clear and unifying strategic directions for NASA—the nation's space and aeronautics agency—or establishing a sound rationale for engaging with the administration and the Office of Management and Budget about out-year funding requirements. The committee also notes that the goals and sub-goals in the strategic plan are not fully supported by NASA's existing program.

Since the end of the Apollo program in the early 1970s, the human spaceflight program has been much more capability driven than mission driven. For example, the Space Shuttle Program was capability driven, in that it was intended to provide a new capability (low-cost transportation to low Earth orbit [LEO]) that was not tied to any particular mission (see Figure 2.1). The Department of Defense (DOD) spent considerable amounts of money to develop shuttle facilities, particularly at Vandenberg Air Force Base, and planned specific satellite deployment missions for LEO. Similarly, the International Space Station (ISS) is a capability—a laboratory in space whose utilization is beginning only now.

During the course of the study, the committee heard that more than 2 years after the President announced the interim goal of sending humans to an asteroid by 2025 there has been little effort to initiate such a mission. There are still no good asteroid targets for such a mission, a necessary prerequisite for determining mission length and details such as the astronauts' exposure to radiation and the consumables required. There is also no indication that NASA is undertaking the sort of comprehensive search necessary to identify asteroid targets. In addition, no hardware, such as a habitation module, is under

FIGURE 2.1 The April 12, 1981, launch at Pad 39A of STS-1, the first space shuttle mission. SOURCE: NASA.

development. The committee also heard from NASA officials that an asteroid mission is more difficult to accomplish and has less utility for developing equipment and operations for an eventual Mars landing mission than they initially believed. For example, unlike a lunar surface mission, an asteroid mission does not result in the development of equipment or operations necessary for eventual Mars missions. While the committee did not undertake a technical assessment of the feasibility of an asteroid mission, it was informed by several briefers and sources that the current planned asteroid mission has significant shortcomings. Despite isolated pockets of support for a human asteroid mission, the committee did not detect broad support for an asteroid mission inside NASA, in the nation as a whole, or from the international community. In contrast, as noted in Chapter 1 (see Box 1.1), three of the last four U.S. presidents (dating back to 1989) have endorsed a mission to Mars as a long-term goal for the human exploration of space.

> **Finding.** *Human exploration.* The committee has seen little evidence that the current stated interim goal for NASA's human spaceflight program—namely, to visit an asteroid by 2025—has been widely accepted as a compelling destination by NASA's own workforce, by the nation as a whole, or by the international community. Although asteroids remain important subjects for both U.S. and international robotic exploration and study, on the international front there appears to be continued enthusiasm for a mission to the Moon but not for an asteroid mission. This lack of consensus on the asteroid-first mission scenario undermines NASA's ability to establish a comprehensive, consistent strategic direction that can guide program planning and budget allocation. The current program has significant shortcomings in the pursuit of the stated goal of the asteroid mission. There has been a long-standing general agreement that a human mission to Mars should be the long-term goal of the human spaceflight program, even though a near-term commitment to such a program is still pending.

In the area of Earth and space science, NASA has clearly demonstrated the success of the strategic planning process that is founded on the National Research Council's (NRC's) decadal surveys. The decadal survey process has matured into a robust method of developing a set of goals and objectives for the Science Mission Directorate's various programs that are based on a scientific community consensus on an achievable suite of science programs in pursuit of high-priority, compelling science questions. However, even the best strategic plan is vulnerable to severe changes in the assumptions that underlie its development, whether those changes are applied internally or externally. As an example, the recent set of surveys on astronomy and astrophysics and on planetary science were based on budget projections provided to the relevant decadal committees, and now these projections exceed the current budget as well as current budget projections. In addition, poor cost control in major missions under development has further strained the budget, with consequences described in Chapter 1.

> **Finding.** *Earth and space science.* Key decadal survey priorities in astronomy and astrophysics, planetary science, and Earth science will now not be pursued for many years, or not at all. The carefully crafted strategic planning process, with its priority setting and consensus building, that has led in the past to the United States leading the world, with science missions such as the Curiosity rover on the surface of Mars and the Hubble Space Telescope, is now in jeopardy because it no longer may lead to a tangible program outcome.

In the area of aeronautics, NASA faces a different set of issues. Although it is difficult and risky to make year-to-year budget comparisons even within agencies such as NASA, because accounting procedures change regularly and therefore budgets do not necessarily include the same assumptions and categories from year to year, it is clear that the NASA aeronautics program has significantly less money now than it did at the end of the 1990s. In 1999, for example, the NASA aeronautics budget was $768.9 million (in 1999 dollars), whereas by FY2012 the budget was $570 million (in current-year dollars). Reduced funding over the past 15 years has necessitated the technical diversification of all of the traditionally "aeronautics" NASA centers (Langley, Glenn, Ames, and Dryden), with increasing proportions of the workforce devoted to programs in human and robotic spaceflight, Earth science, and space technology. While this is not necessarily a bad thing, it seems highly inefficient to redirect scientists and engineers to work on programs for which greater expertise lies at another center, and not to have those scientists and engineers pursue R&D in areas for which they have facilities and expertise and for which there are clear national needs. The current priorities of the Aeronautics Research Mission Directorate include a number of these areas of national need, such as ambitious programs in fundamental, cutting-edge aircraft technologies; systems-level integration for Next Generation Air Transportation Systems (NextGen), including air traffic management; and green aviation/energy efficient aircraft (NASA, 2012a). Yet with a limited budget and aging infrastructure, including national assets such as wind tunnels and flight test vehicles, the maintenance of a robust aeronautics program is highly challenging.

During the course of its deliberations, the committee did not hear a clear rationale for the overall decline in NASA aeronautics spending during the past 10-12 years. In some cases, it appears as if shortfalls in other NASA budgets, such as human spaceflight, resulted in reductions in the aeronautics budget to pay for them. In other cases, such as recent proposals to essentially eliminate NASA's hypersonics research budget, it appears as if there may have been external leadership decisions beyond NASA that led to focusing that research at DOD, without any clear explanation of rationale. Although the committee's statement of task did not allow it to recommend budget levels, the committee did conclude that an important federal resource was being underutilized and slowly atrophying without clear recognition or explanation.

Finding. *Aeronautics.* The NASA aeronautics program historically has made important contributions to national priorities related to the U.S. air transportation system, national defense, fuel-efficient air vehicles, and those portions of the space program that include flight through Earth's atmosphere. Despite continued requirements for the development of highly efficient aircraft, alternative aviation fuels, safe air traffic systems, and other high-priority areas, budget cuts have limited NASA's role in solving these important problems. The committee therefore finds that the full potential of the aeronautics program is not being achieved.

The FY2011 budget request for NASA projected that the Space Technology Program would receive a budget of just over $1 billion annually from FY2012 through FY2016 (OMB, 2011). Congress responded by providing little more than half of the requested amount (P.L. 112-55, 2011), and the FY2013 budget request for NASA is now projecting reduced expectations of $700 million annually (OMB, 2012). Even if Congress were to provide more funding in FY2013 than it did in FY2012, it would be difficult to support substantial research across the broad scope that NASA has established for the Space Technology Program. The Office of the Chief Technologist, which manages the Space Technology Program, has drafted individual technology development roadmaps for 14 distinct technology areas that it expects the Space Technology Program to investigate. These technology areas include ground systems, launch systems, spacecraft, human health, robotics, descent and landing systems, and other related technologies (NASA, 2012). A recent report by the NRC identifies the highest-priority technologies among the 320 technologies addressed in NASA's 14 draft roadmaps (NRC, 2012).

Finding. *Space Technology.* The recently established Space Technology Program has carried out a roadmapping and priority-setting strategic planning process, assisted by the NRC, but the program is yet to be funded at the levels requested by the President's budget.

MISMATCH BETWEEN NASA'S BUDGET AND PORTFOLIO

The committee has examined the current NASA budget and found that it is mismatched to the current portfolio of missions, facilities, and staff. This mismatch reduces NASA's ability to achieve the broad scope of activities it is directed to address. In addition, suboptimal effectiveness and efficiency is one byproduct of an amorphous mission statement. This problem is sometimes exacerbated when NASA pursues highly challenging technological programs (such as the space shuttle, the ISS, and the James Webb Space Telescope), with initial budgets that prove to be far too little to complete the missions. This situation occurs, in part, because the current approach to approving and funding projects incentivizes overly optimistic expectations regarding cost and schedule (NRC, 2010). In the end, if NASA fails to deliver, it earns a reputation for over-promising and underperforming. On the other hand, if a major mission meets or exceeds expectations, cost overruns may be forgotten.

There are likely to be opportunities for more cost-efficient management of the NASA budget—through, for instance, allowing NASA to adjust the size of its civil service workforce as needed, streamlining infrastructure, greater reliance on cost-shared partnerships, and directly addressing the factors that lead to cost overruns (NASA, 2010). However, there remains significant uncertainty as to whether NASA will be able to obtain budget increases to more effectively and efficiently implement its current program portfolio, or whether programs need to be terminated or restructured in order to achieve a healthy program portfolio within the current budget level. Tighter budget constraints highlight fundamental choices within the program portfolio, particularly with regard to the relative emphasis and funding among the human exploration, space science, Earth science, aeronautics, and technology development programs. This points to the critical need for a strategic plan that has clear priorities and a transparent budget allocation process.

While robotic exploration is a necessary precursor to human exploration of, say, Mars or an asteroid, possibly decades of investment are required to overcome the extraordinary technological challenges in protecting humans transported to and from Mars (both from radiation and the effects of microgravity or partial gravity), potentially costing hundreds of billions of dollars, if not more (Weaver and Duke, 1993; NRC, 2011). The design and development costs of a heavy-lift launch vehicle are particularly high, which is a primary reason why recent designs have evolved from legacy systems (as are both former Constellation and present Space Launch System [SLS] vehicles). In addition, launch vehicle programs are most successful and affordable when there are multiple launches to amortize the cost of infrastructure and the personnel required to build and operate them. That is problematic for the heavy-lift vehicle unless NASA can develop multiple users either internally (i.e., science programs) or externally, such as DOD or international customers. Doing so may be challenging for the simple reason that large payloads that could use the SLS tend to be expensive payloads, which are rare.

At the time of its review of NASA in October 2009, the Augustine Committee stated that "… no plan compatible with the FY2010 budget permits human exploration to continue in any meaningful way." The Augustine committee concluded that in order for NASA to pursue a mission of sending humans beyond low Earth orbit, NASA required additional funding of $3 billion more per year. For human exploration of an asteroid and then Mars, even within a few decades, it is not clear that even $3 billion per year is sufficient.

NASA is currently engaged in public-private partnerships in which it funds industry to develop new launch vehicles and transportation systems to meet NASA requirements (currently in low Earth orbit), while giving industry a broad flexibility to design a vehicle that will meet those requirements. According to NASA its Commercial Crew and Cargo Program aims "to stimulate efforts within the private sector to develop and demonstrate safe, reliable, and cost-effective space transportation capabilities."[1] The program manages the Commercial Orbital Transportation Services (COTS) partnership agreements with U.S. industry, initiated in 2006, totaling $800 million for cargo transportation

[1] See http://www.nasa.gov/offices/c3po/home/.

demonstrations. When requested, NASA also contributes technical expertise assistance.[2] Among recent successes, for example, under NASA's Commercial Resupply Services program, the SpaceX Falcon 9 medium-lift launch vehicle and Dragon spacecraft demonstrated successful berthing and cargo delivery to and return from the ISS. NASA anticipates that this approach will reduce costs to the government relative to a traditional acquisition process, but the final cost results are incomplete. Encouraging the development of space transportation capabilities with reduced government involvement is valuable to the United States in its own right in building an eventual commercial space industry that can serve customers other than NASA, but it has not yet been demonstrated that it will be a reliable strategy to reduce NASA's costs. NASA has historically developed specific rocket launch vehicles (e.g., the Saturn V, the space shuttle, and SLS under development) for its human spaceflight program. Other domestic launch vehicles such as the Pegasus, Delta II, and Atlas V have been used for NASA's other space missions, hence NASA's substantial historical investment in launch systems has been almost exclusively for human space exploration. DOD has not made use of NASA launch vehicles for military missions to any significant degree other than the space shuttle during a short period of time. This is in part because there have been distinct heavy-lift requirements for NASA and DOD missions, but this also arises from historically negotiated differences in emphasis between NASA and the DOD on reusable versus expendable systems.

Recent advances in new NASA-sponsored "commercial" launch ventures have been promising for restoring access to the ISS using domestic launchers. NASA still requires a heavy-lift launch vehicle for human exploration beyond low Earth orbit, and it is possible that at least one of these "commercial" launch vehicle systems currently focused on the ISS could evolve to having heavy-lift capability. Given the commonalities in technology and industrial base, as well as similarly high standards for mission assurance, coordinated development of new launch vehicles by NASA and DOD may be a more effective approach to advancing U.S. competence in launch vehicle technologies.

Currently, space operations and exploration programs that encompass the agency's human spaceflight activities constitute nearly half of the NASA budget, while Earth and space science constitutes 29 percent of the budget and aeronautics constitutes just 3 percent of the budget. (See Figure 2.2.) These percentages are modified to a degree by the uneven distribution of cross-agency support among the centers.

Finding: NASA's budget has been remarkably stable at the top level for more than a decade. However, there has been some instability at the programmatic level and the out-year projections in presidential budget requests are unreliable, which makes it difficult for program managers to plan activities that require multi-year planning.

Finding: With the current available budget-driven approach, intermediate milestones and completion dates for some programs have been delayed. This in turn results in a lack of tangible near-term performance outcomes from cost-inefficient programs that only extend the lifespan of fixed and indirect costs.

Finding: Stretching programs out limits opportunities for NASA to develop and incorporate new technology into program architectures.

[2] See http://www.nasa.gov/offices/c3po/about/c3po.html.

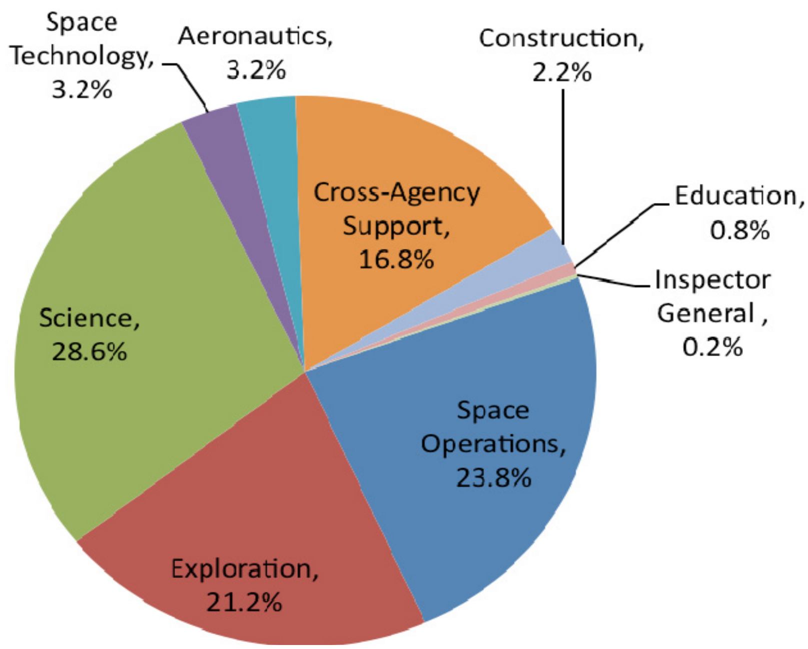

FIGURE 2.2 NASA budget allocation, FY2012. SOURCE: Consolidated and Further Continuing Appropriations Act (2012, P.L. 112-55, 2011).

Conclusion: There is a significant mismatch between the programs to which NASA is committed and the budgets that have been provided or anticipated. The approach to and pace of a number of NASA's programs, projects, and activities will not be sustainable if the NASA budget remains flat, as currently projected.[3] This mismatch needs to be addressed if NASA is to efficiently and effectively develop strategic directions of any sort.

Conclusion: To reduce the mismatch between the overall size of its budget and NASA's current portfolio of missions, facilities, and personnel, the White House, Congress, and NASA, as appropriate, could use any or all of the following four (non-mutually exclusive) options. The committee does not recommend any one option or combination of options but presents these to illustrate the scope of decisions and tradeoffs that could be made. Regardless of the approach or approaches selected eliminating the mismatch will be difficult.

Option 1. Institute an aggressive restructuring program to reduce infrastructure and personnel costs to improve efficiency.

Option 2. Engage in and commit for the long term to more cost-sharing partnerships with other U.S. government agencies, private sector industries, and international partners.

Option 3. Increase the size of the NASA budget.

Option 4. Reduce considerably the size and scope of elements of NASA's current program portfolio to better fit the current and anticipated budget profile. This would require reducing or eliminating one or more of NASA's current portfolio elements (human exploration, Earth and space science, aeronautics, and space technology) in favor of the remaining elements.

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[3] For example, if the budget falls, in constant dollars, from $18.4 billion in FY2011 to $16.6 billion in FY2017, in FY2011 dollars.

The committee recognizes that attempting to eliminate the mismatch between the overall size of the NASA budget and its current portfolio of missions, facilities, and staff using any one of the above options, or even several options in combination, would be difficult programmatically and politically. While joint development and cost sharing have been pursued in the past, partnerships between NASA and other U.S. government agencies as well as those between NASA and international entities have not always proceeded smoothly, and in some cases have not been successful. Yet, implementing some of the options could have far-reaching consequences for NASA's current and future ability to achieve important goals in one or more of the agency's core mission areas. The ultimate impact of this budget-portfolio mismatch will likely be far greater unless it is addressed comprehensively and strategically rather than in an ad hoc fashion, year by year.

Various organizational restructurings exist for NASA, although the committee was unaware of any detailed study of them and is not endorsing such an option, only noting that it exists. Naturally, it would require careful thought.

Cost-sharing partnerships can take many forms. For example, NASA's Stennis Space Center currently shares facilities costs with other government tenants such as the U.S. Navy; NASA and the U.S. Air Force have jointly developed and tested research aircraft; and NASA is developing commercial cargo and commercial crew capabilities where private industry provides some of its own money for development, based on the assumption that a new market will emerge.

Each of the above options, with the possible exception of Option 2, would require legislative action. Every option except for Option 3 would require substantial changes within NASA in order to substantially address the mismatch between NASA programs and budget. Before any of those options are implemented, the advantages and disadvantages, including possible unintended consequences, deserve careful consideration. For example, if not handled carefully, Option 1 could constrain future mission options or increase future mission costs if unique facilities needed by future missions are decommissioned. Option 1 might also diminish NASA personnel capabilities if changes in policies prompted large numbers of key personnel to retire or seek other employment. To be effective, Option 2 may require congressional authorization for NASA to make long-term financial commitments to a particular program to assure prospective partners that neither NASA nor the Congress will unilaterally cancel a joint program. Option 3, of course, is ideal from NASA's perspective, but it also seems unlikely given the current outlook for the federal budget. Option 4 is perhaps the least attractive, given the value of each major element in NASA's portfolio.

In addition, there is also the question of balance among major NASA activities. For example, should the agency spend as much money as it currently does on space and such a small percentage on aeronautics, or should they be adjusted? For every dollar that NASA spends on aeronautics, it spends $23 on space-related activities (space operations, exploration, science, and technology).

Although the committee has identified significant impacts of current budget constraints on the individual programs at NASA and has described the kinds of options that would have to be considered to address the mismatch between the scope of NASA's programs and the budget, it has not attempted to judge the appropriateness of the distribution of resources among these programs. Moreover, it would have been difficult to do so because of the absence of stated priorities that would provide a framework for making that assessment. The committee was not tasked with making such judgments.

ESTABLISHING A STRATEGY AND STRATEGIC VISION FOR NASA

The committee's statement of task requires the committee to recommend how NASA could establish and effectively communicate a common, unifying vision for NASA's strategic direction that encompasses NASA's varied missions (Appendix A). In some ways this task is based on a flawed premise, for NASA does not set its own vision. NASA is the *National* Aeronautics and Space Administration, and it implements the nation's strategic direction for aeronautics and space activities under its purview. The nation's vision for NASA is properly set by the White House and Congress on behalf of the American people. NASA implements a strategy based on policies and laws—including budgets—set by the White House and Congress with regard to the two largest elements of NASA's program. The decadal surveys for NASA's science mission describe the scientific consensus for future missions in that area, but a clear consensus does not exist with regard to human exploration. Conventional wisdom is that the nation's vision for human spaceflight is set by a President in a major speech and supported by Congress thereafter. That example has only worked once (for the Apollo program, although even during Apollo there was considerable skepticism expressed by some members of Congress and the public).

NASA and the nation would also be well-served by adopting a set of strategic goals and objectives that are clearly defined so that they effectively communicate the agency's priorities. Currently, some of the goals and outcomes in the *2011 NASA Strategic Plan* are so vague as to provide little practical information on the intended direction or priorities of NASA programs (see Box 1.2).

> **Conclusion:** There is no national consensus on strategic goals and objectives for NASA. Absent such a consensus, NASA cannot reasonably be expected to develop enduring strategic priorities for the purpose of resource allocation and planning.

> **Recommendation:** The administration should take the lead in forging a new consensus on NASA's future that is stated in terms of a set of clearly defined strategic goals and objectives. This process should apply both within the administration and between the administration and Congress and should be reached only after meaningful technical consultations with potential international partners. The strategic goals and objectives should be ambitious, yet technically rational, and should focus on the long term.

> **Recommendation:** Following the establishment of a new consensus on the agency's future, NASA should establish a new strategic plan that provides a framework for decisions on how the agency will pursue its strategic goals and objectives, allows for flexible and realistic implementation, clearly establishes agency-wide priorities to guide the allocation of resources within the agency budget, and presents a comprehensive picture that integrates the various fields of aeronautics and space activities.

> **Recommendation:** NASA's new strategic plan, future budget proposals prepared by the administration, and future NASA authorization and appropriation acts passed by Congress should include actions that will eliminate the current mismatch between NASA's budget and its portfolio of programs, facilities, and staff, while establishing and maintaining a sustainable distribution of resources among human spaceflight, Earth and space science, and aeronautics, through some combination of the kinds of options identified above by the committee. The strategic plan should also address the rationale for resource allocation among the strategic goals in the plan.

The defined goals and objectives will be most effective if they also include the logical stepping stones that reach the overall final goal. If such a direction is clearly defined, then NASA can define and implement a strategy that will clearly lay out priorities and pathways to achieving the goals and objectives on which the nation has agreed. To be of real utility to NASA and the nation, a comprehensive, long-term strategy for NASA would have to include the following considerations:

Benefit. Define the potential technical and societal benefits for the major programs and initiatives in each mission area (human exploration, science, aeronautics, and technology development). in the near and far term. Identify how well each program and initiative lines up with NASA needs, non-NASA aerospace missions and requirements, and U.S. scientific and technological capabilities.

Integration. Describe how the strategy for each NASA mission area fits together to support each other as well as the agency's strategic goals and objectives.

Scientific and engineering excellence and innovation. Describe a process for ensuring that major NASA missions have access to world-class scientific and engineering excellence, whether that excellence is located within NASA, at other domestic organizations in government, industry, and academia, or among NASA's current or potential international partners.

Credibility. Describe a process for ensuring that the strategy is based on realistic estimates of requirements, costs, schedules, risks, and overall level of effort.

Global in perspective. Describe plans for including international partners in major programs whenever such partnerships would provide significant benefits in terms of key factors such as mission value, cost, schedule, or risk.

Interagency collaboration. Describe plans for including other parts of the U.S. government.

NASA'S CONTRIBUTIONS TO NATIONAL PRIORITIES

The White House's Office of Science and Technology Policy (OSTP) notes the national importance of investments in science and technology as "engines of discovery" that will "expand the frontiers of human knowledge, promote sustainable economic growth . . . and reinforce our national security" (OSTP, 2012). OSTP identifies NASA as one of the federal government's key research agencies, and the President's FY2013 budget proposes a 2.2 percent increase in the budget for NASA's research and development portfolio, to a total of $9.6 billion. This investment is well justified given the unique role that NASA plays in the nation's science and technology program. For example, there is information which can only be obtained with space-based instruments. In addition, the human spaceflight program provides a basis for advancing science (such as life and microgravity research conducted on the International Space Station) while achieving closer international relationships with program partners and thus contributing to broader foreign policy objectives. The aeronautics program advances the state of the art in many aeronautical disciplines in a sector of great value to the national economy and national security. Earth and space science missions contribute to the stewardship of our planet and the advancement of knowledge while developing high resolution sensing, robotic, and related technologies; an example of a National Oceanic and Atmospheric Administration (NOAA) GOES weather satellite image is shown in Figure 2.3. Furthermore, NASA programs interact with strategically important sectors of the economy due to the need for technical know-how and advanced industrial capacity to design, engineer, and build NASA systems and instruments.

NASA has numerous roles and responsibilities in many important U.S. multi-agency activities such as National Security (DOD—aeronautics, space sensors and coordinated development of new launch vehicles, and space weather) (NRC 2004), Earth and space science (the National Science Foundation's [NSF's] significant role in the Antarctic and ground-based telescopes, NOAA's work in the oceans and the atmosphere), national airspace issues (the Federal Aviation Administration, the Department of Homeland Security, and other agencies involved in regulating and monitoring airspace), and technology development (NSF, the National Institutes of Health, DOD).

Because the responsibilities of government agencies overlap, and there is already significant coordination and cooperation among them, the United States would be best served if the government agencies with responsibilities in aeronautics and space were to collaborate in the process of establishing strategic goals and objectives and in the planning and implementation of appropriate programs. How this can best be done, and what the coordinating authority and the organizing principles should be, is complex, unclear, and beyond the scope of this study. In the past, a National Space Council has been used for this purpose, particularly during the period 1989-1992. An effective coordinating authority will depend on the interests of a particular administration and cannot be imposed upon an administration that does not agree with its goals. Nevertheless, it seems that in an increasingly constrained budget environment the government can achieve greater efficiency by operating its agencies in a coordinated manner.

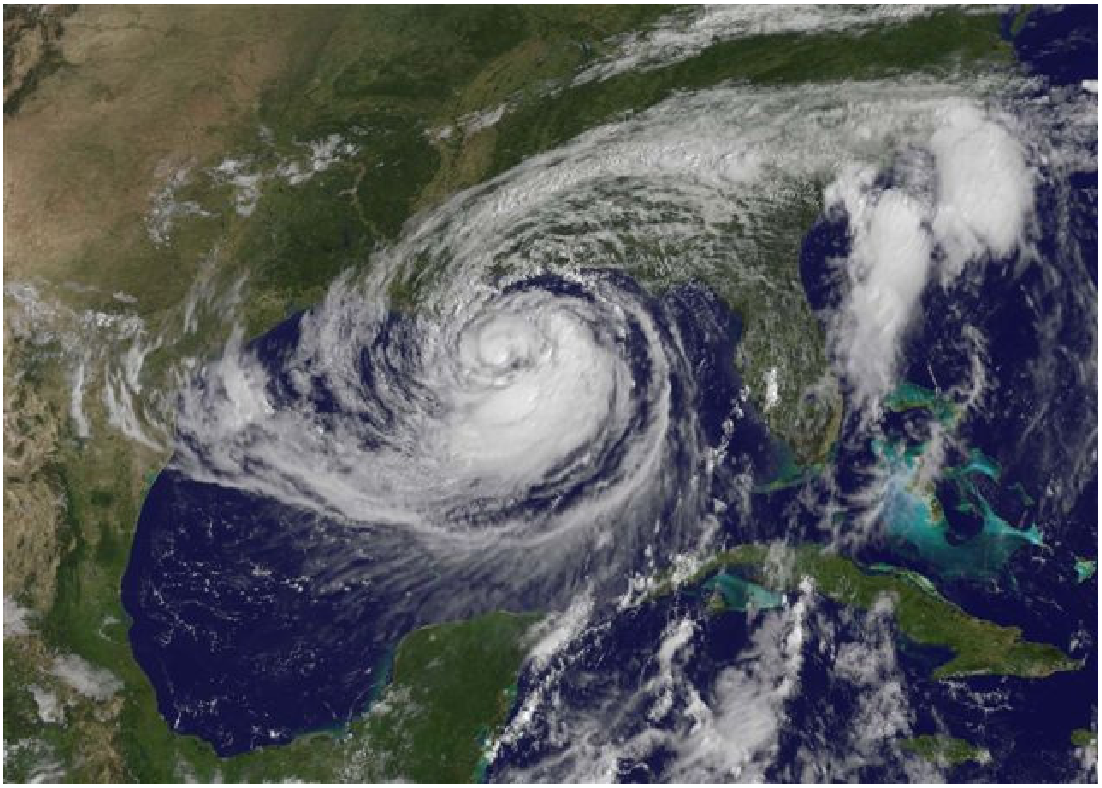

FIGURE 2.3 This visible image of Tropical Storm Isaac taken from NOAA's GOES-13 satellite shows the huge extent of the storm, where the eastern-most clouds lie over the Carolinas and the western-most clouds are brushing east Texas. SOURCE: NASA GOES Project.

> **Recommendation:** NASA should work with other U.S. government agencies with responsibilities in aeronautics and space to more effectively and efficiently coordinate U.S. aeronautics and space activities.

In the past half century, NASA's achievements have contributed to economic and national security and national pride and prestige. NASA programs assert U.S. scientific and technological leadership, improve international relationships, and advance U.S. foreign policy objectives. A 2009 NRC report, *America's Future in Space: Aligning the Civil Space Program with National Needs,* concluded that a preeminent U.S. civil space program "is a national imperative" that "should be preeminent in the sense that it can influence, by example, nations' use of space."

The *2011 NASA Strategic Plan*, while providing for NASA to continue its work as an "engine of discovery," lacks a clear statement on the role of NASA with respect to the civil space programs of other nations. Maintaining U.S. leadership in space contributes to many important national priorities as noted above and relies on two major assets. Firstly, leadership depends on science and technological excellence as demonstrated by flagship missions (with budgets of many billions of dollars each) such as the Hubble Space Telescope, the James Webb Space Telescope, or the Curiosity rover, and by small Explorer, Discovery or New Frontiers style missions. (See Figure 2.4.) Secondly, leadership relies on strong ties with the international community of stakeholders.

FIGURE 2.4 Edge-on image of the Sombrero spiral galaxy captured by the Hubble Space Telescope. SOURCE: NASA.

INTERNATIONAL COOPERATION AND U.S. LEADERSHIP

An additional important aspect of NASA addressing national priorities is the agency's role in demonstrating and maintaining U.S. global leadership particularly in Earth and space science and human spaceflight. The United States has consolidated its leadership in space since the early days of NASA through the era of the space shuttle, the Hubble Space Telescope, and the ISS. (See Figure 2.5.) NASA has established more than 3,000 international agreements since 1958 with more than 100 nations. Today nearly 600 international agreements are in place; half of them are with France, Germany, the European Space Agency, Japan, the United Kingdom, Italy, Canada, and Russia; the other half are with countries with less advanced space programs who value the opportunity to benefit from U.S. leadership in space. Two-thirds of those agreements support science missions at NASA. At the same time, the number of space-faring nations has been increasing steadily and the gap between their capabilities and those of the United States appears to be narrowing. All of the countries of the world, including potential strategic rivals on other fronts, are potential partners in the space arena. Cooperation and collaboration are becoming commonplace and increasingly important with international partners playing, or likely to play, roles that include those on the critical path to a mission's success.

As stated earlier, although the United States has long led in space exploration, its position has slipped. Russia has significant capabilities in space transportation but is not substantively pursuing areas such as human transportation beyond LEO. Europe has concentrated on developing a relatively small industrial activity in space and, as a result, ranks first in commercial satellite production and launches, as well as having developed a significant program in Earth and space science. China, Japan, and India also have significant space programs focused on developing indigenous launch vehicles and conducting programs in space science and applications. China and Japan also have strong human spaceflight programs. China has developed its own capabilities, while Japan cooperates with the United States and other countries in the ISS program. All three are part of the 14-member International Space Exploration Coordination Group that meets to discuss future human spaceflight exploration plans.

FIGURE 2.5 A composite of a series of images photographed from a mounted camera on the Earth-orbiting International Space Station from approximately 240 miles above Earth. SOURCE: NASA.

There is in fact an inherent tension between the desire of countries—including the United States—to develop and demonstrate their technological and political strength with their space programs and the desire for and opportunities provided by international cooperation. At times developing space powers may wish to "go it alone" in order to advance and demonstrate their capabilities, but later seek to join in cooperative efforts with longstanding space powers as a means of demonstrating that they are now on a near-equal status. The opportunities for international cooperation are fluid and sometimes fleeting.

The success of NASA's long-term strategic planning in Earth and space science based on the community-consensus-driven NRC decadal survey process has led the agency to be the leader in space science through the series of missions, many of which have been international collaborations with the United States in both leading and minority roles. Space science missions such as the Hubble Space Telescope, the Cassini-Huygens mission to Saturn and Titan, and the Mars Curiosity rover show how U.S. leadership can harness the impressive capabilities of many countries to successfully advance understanding of the solar system and the universe.

In the area of Earth and space science, the recent abandonment by NASA of well-established partnerships—for instance, with the European Space Agency—will potentially undermine the prospects for continuing the kinds of cooperation that will be required to carry out the next generation of large, complex strategic science missions that the science communities in the United States, Europe, and elsewhere agree are the next steps in unraveling the mysteries of our solar system, our galactic home, and the cosmos. Projects such as Mars sample return, future missions to the outer planets and their moons, and the next generation of space telescopes will need to be executed by international consortia. But unless NASA can address cost overruns and the United States can address budget shortfalls, which have resulted in there being little funds to pursue the next generation of ambitious international space science missions, the success of the international approach to demonstrating U.S. leadership in this field will be in jeopardy.

In human spaceflight, NASA has been at the forefront of the effort by successive administrations and Congress to advance national security and foreign policy goals by means of the projection of U.S. soft power through efforts such as the construction and operation of the ISS. The ISS experience demonstrates how the United States assuming the role of a "managing partner" in a large, complex international endeavor that encompasses both considerable technical challenges as well as considerable cultural, legal, and political barriers can promote the United States' overall standing in the world, while also achieving key scientific and geo-political priorities. The ISS represents one model, and by no means, the only model, for broad international cooperation. This has also come with a price, both in terms of the expense of building the ISS and the ongoing cost of operations.

One of the United States' greatest space accomplishments was the Apollo Moon landings, which in many ways has shaped, and perhaps distorted, the way that we look at human spaceflight, including the role of cooperation and competition. The lunar landing goal was established in a competitive environment, with the United States seeking to beat the Soviet Union to landing a human on the lunar surface. Advocates of competition occasionally still point to Apollo as an example of what can be accomplished when external factors force the United States to strive harder. One of the rhetorical questions posed to the committee was what will be the position of the United States "when in 2025 the Chinese land on the Moon?"[4] This question is occasionally raised as a justification for increasing NASA funding. At the moment, this is an entirely hypothetical scenario, because China has no stated plans for sending humans to the Moon, let alone by a specific date. However, the question is also useful for focusing thinking about the larger international context for NASA's activities. Unlike the Apollo era, today the United States could respond in various ways to such a possible challenge, including indifference (noting that the United States was already on the Moon in 1969), or alternatively engaging in a "race" with the Chinese. Further internationalization of the space program offers an alternative approach—one that could also guarantee that the U.S. maintains its traditional and long-established role as the global leader in space. Thus, whereas competition offers one path to demonstrating leadership, cooperation can offer another path. International cooperation would still leave room for healthy competition, particularly depending on which partners the United States chooses.

Today, as mentioned above, the international context is changing rapidly, however, in this changing world the role for the United States remains to lead. But a new paradigm for leadership is required where partners are given a more equal voice and a more substantive role in key areas critical to mission success. To lead is not necessarily *to command* and it is possible to establish international partnerships where all the members take part in major decisions and their interests are clearly aired and considered. A more collaborative approach can lead to a program where each partner can mobilize various capacities for a specific purpose in line with its national interests while in pursuit of a common goal. Indeed, given the world economic situation, this may be imperative for engaging the taxpayers of our international partners. The United States can advance its national goals in space by sharing the responsibility on a global scale—making the United States a real leader among a host of nations contributing to space exploration and reaping the benefits.

Indeed such an internationalization of the pursuit of this nation's goals in human spaceflight is likely to be a requirement for any successful pursuit of NASA-led missions to an asteroid, the Moon, and eventually Mars and its moons. This is inherently recognized through NASA's participation in the International Space Exploration Contact Group—a non-binding process for dialog involving many of the world's space agencies on establishing future pathways for human exploration.

However, a note of caution is still called for. International missions can cost as much or more than the equivalent mission would have cost if done by the United States alone. In addition, U.S. laws and regulations, such as the International Traffic in Arms Regulations, can greatly complicate international cooperation. For modest projects, the added complexity of a large international effort can easily make things more expensive and slower to complete. There are various models of cooperation that may be more useful in the future, but it will depend on the specific requirements at the time as well as the interests of the countries willing to engage in cooperation. A creative approach is needed for NASA to elaborate the new models adopted by the modern international situation.

[4] This comment was made to the committee by former NASA Administrator Michael Griffin.

Finding: The capabilities and aspirations of other nations with respect to space have changed dramatically since the early days of the space race between the Soviet Union and the United States.

Finding: One of the most important successes of the International Space Station was its international character and the role of the United States as the managing partner in a global enterprise.

Finding: If the United States seeks to undertake a human mission to Mars, such a mission will undoubtedly require the efforts and budgets of many nations.

Conclusion: There is an opportunity for the United States to use its well-established record of accomplishment in space, its impressive capabilities, and its role as an international managing partner to lead a more international approach to future large space efforts, both in the human space program and in the science program.

Recommendation: The United States should explore opportunities to lead a more international approach to future large space efforts both in the human space program and in the science program.

If extending human presence beyond low Earth orbit remains part of NASA's strategic goals and objectives, the United States could take the lead in establishing a global vision for the future of human exploration, which would be a long-term international venture that builds on the success of the ISS partnership and includes all willing space powers. (See Figure 2.6.)

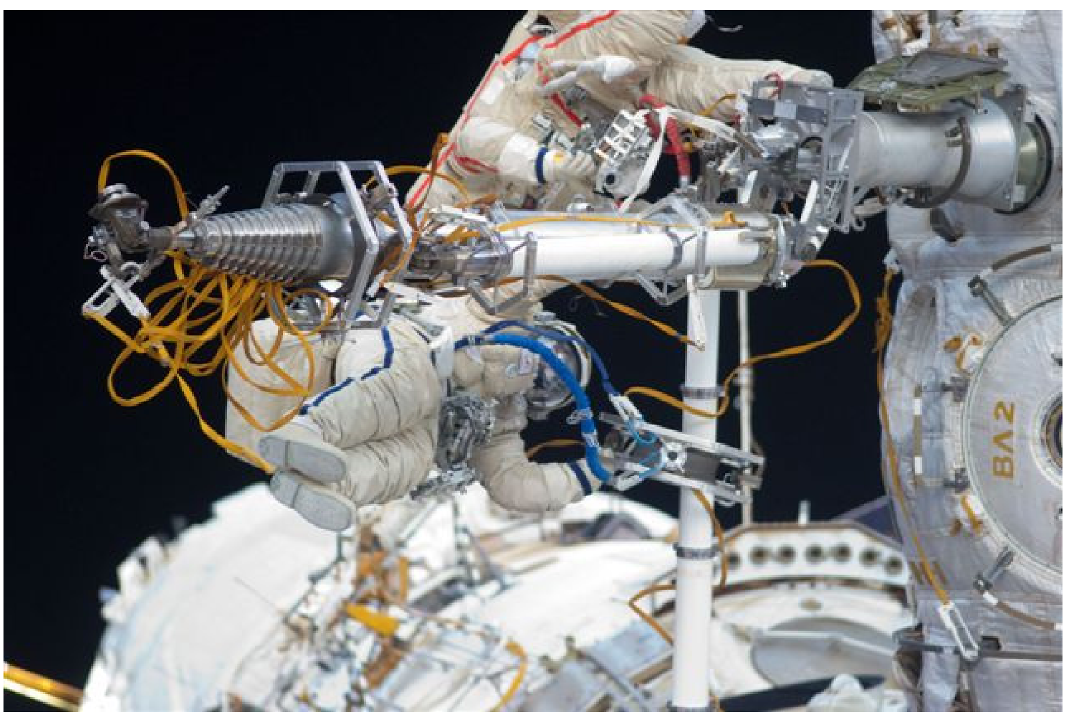

FIGURE 2.6 Russian cosmonauts Gennady Padalka, Expedition 32 commander, and Yuri Malenchenko, flight engineer, participate in a nearly 6-hour session of extravehicular activity to continue outfitting the International Space Station on August 20, 2012. SOURCE: NASA.

However, U.S. leadership in international space cooperation requires meeting several conditions. First, the United States has to have a program that other countries want to participate in. That includes bold goals, but also goals that are consistent with those of potential partners (for example, international interest is greater in lunar exploration than in NASA's chosen asteroid mission). Second, the United States has to be willing to give substantial responsibility to its partners. In the past, the approach of the United States to international partnership has too often been perceived as being based on a program conceived, planned, and directed by NASA. Third, other nations must be able to see something to gain, in other words, a reason to partner with the United States. Finally, the United States has to demonstrate its reliability, including budget stability over time. A perception among potential partners that NASA's budgets for international programs fluctuate too wildly will naturally make them reluctant to cooperate. These are not the only requirements, but they are the primary ones.

EXAMINING NASA'S INSTITUTIONAL STRUCTURE

The lack of national consensus on the future for NASA human exploration and the agency as a whole, as well as the mismatch between the NASA budget and NASA's current portfolio of missions, facilities, and staff, contribute to serious problems facing NASA, including substantial deferred maintenance on infrastructure, inability to maintain core competencies within the government for key space technologies and operations, and an approach to downsizing that attempts to spread work and projects over infrastructure and a personnel force that are larger than required. As noted below, however, NASA's options are limited because it lacks adequate flexibility to fully address infrastructure and personnel issues because of civil service regulations, legislative mandates that impose additional limitations, and requirements on valuing unused/unneeded facilities.

During the course of this study, members of the committee visited all nine NASA field centers plus the Jet Propulsion Laboratory.[5] The visits revealed that the centers share many of the same issues, such as aging facilities, program instability, and confusion about their future. But the visits also revealed that each center is unique, with its own strengths, areas of expertise, and problems. Thus, one lesson that the committee has drawn from its visits is that there is no one-size-fits-all policy or regulatory change that can serve all of the centers. Indeed, such an approach has the potential to do more harm than good.

Finding: Different policies and regulatory changes have to be applied to different NASA centers. There is no realistic "one-size-fits-all" approach.

One primary question that the committee asked itself was whether NASA's overall structure of field centers was still valid. Multiple field centers were established during the early years of the space race for different reasons, including supporting regional economic development and increasing political support for NASA. However, the committee notes that although many of those initial reasons for establishing and distributing the centers are no longer valid, there remain benefits to having a dispersed field center structure as well as occasional redundancy among field centers. The United States has substantial geographical diversity in terms of its natural resources, economic development, and intellectual resources. There are benefits to having facilities spread around the country where they can tap into localized talent. However, this also makes it more difficult for NASA to manage its centers

[5] Ames Research Center, Dryden Flight Research Center, Glenn Research Center, Goddard Space Flight Center, the Jet Propulsion Laboratory, Johnson Space Center, Kennedy Space Center, Langley Research Center, Marshall Space Flight Center, Stennis Space Flight Center. In addition, during the visit to Glenn Research Center, members of the committee also visited the nearby Plum Brook Station, which has recently undertaken work for the European Space Agency and may soon be providing its facilities to other international and commercial partners on a reimbursable basis.

efficiently, because agency leadership has difficulty transferring personnel and work and closing facilities due to local opposition.

NASA's institutional infrastructure was largely defined to support legacy organizations such as the Apollo program and the National Advisory Committee for Aeronautics. NASA as a whole and many centers in particular have made a number of changes over the years in seeking to realign the agency's institutional infrastructure to its changing mission and priorities. However, it appears that the institutional infrastructure remains too large for efficient execution of currently envisioned programs. As a result, NASA has underutilized facilities, significant deferred maintenance and modernization costs, and workforce skill maintenance issues. It is difficult to maintain skills in some areas in the absence of meaningful work, and institutional memory is lost when existing staff retire without experienced replacements available. These problems have been exacerbated by the termination and cancellation of major space exploration programs.

The distribution of work among NASA centers in recent years has favored the sustainment of all the centers (and JPL) over establishing and maintaining centers of excellence for retention of critical skills and capabilities. This has in part resulted from legislative requirements to maintain the current geographic distribution of the large civil service component of the NASA workforce and the legal prohibition on NASA from applying regular reduction-in-force (RIF) governmental policies to its civil servants. As a result, some civil service staff are retained even when they are no longer needed at their assigned center.

Civil service rules, as well as additional legislative workforce restrictions placed upon NASA, contribute to large fixed costs and hamper efficient tailoring of the workforce to meet current skill retention requirements or expansion to new technical areas. A "one-size-fits-all" workforce model is problematic given the wide disparity between centers that are focused on R&D, centers that are focused on operations, and centers with more of a mixed portfolio. For example, the JPL is an FFRDC, and some have suggested that it would be a viable model for NASA field centers. However, JPL has a relatively narrowly focused mission compared to many of the field centers, and it works well as an FFRDC in part because it started as an FFRDC, so its model may not apply to centers that have had a different heritage. In some cases, it may be appropriate to downsize certain centers from multi-purpose facilities to single-purpose facilities, organized where unique test facilities are housed, and in other cases to evolve from a single-purpose facility—like a space shuttle launch site—into a multi-user facility.

In other cases, for example, with centers that have large research (as opposed to operational) responsibilities, it may be appropriate to consider the feasibility of applying some of the authorities granted for civil servants in other parts of the U.S. government and/or converting all or part of the center to a FFRDC model. For example, "a center within a center" could be set up in some cases to provide a core operational capability staffed by civil servants with the rest of the work force operating as an FFRDC. This committee recognizes the extraordinary challenges that such a conversion could entail and that conversions have been recommended and rejected in the past (for example, the 2005 Aldridge Commission report). But the current economic challenges call for all logical management structures to be explored, and at the very least a transition to greater flexibility in managing its centers could have tremendous benefits for NASA. The Cross Agency Support budget funds NASA operations, including the construction of facilities and infrastructure, to provide capabilities that cannot be tied directly to the needs of a particular program. Cross Agency Support also funds environmental compliance and restoration activities. However, the essential role and value of the Cross Agency Support budget does not seem to be fully appreciated by Congress. Because of this lack of clarity and because of the size of the Cross Agency Support budget, it is an easy target when funds are needed to cover shortfalls in the mission areas.

Lessons learned from current efforts by individual centers to improve their efficiency, effectiveness, and strategic direction could be considered for broader implementation at other centers. Lessons can also be learned from other parts of the federal R&D system, such as the Department of Energy's (DOE's) Office of Science, which manages 10 national laboratories, each of which has a major steward or sponsor within the Office of Science. These laboratories appear to be managed as a system of centers in pursuit of the Office of Science's strategic goals. Some of NASA's unique testing facilities could be designated as National User Facilities, to be available for both NASA and non-NASA testing. These facilities could have their own operating and maintenance budgets that would not be tied to the budgets of cognizant centers or individual NASA programs.

In many cases, individual NASA centers are taking action to selectively reduce their infrastructure, or to find alternative ways to support it. For example, during a visit to the NASA Plum Brook facility, members of the committee heard about industrial and international use of the test facilities. During a visit to the Kennedy Space Center, members of the committee heard about efforts to attract industry to use buildings and equipment no longer required for the space shuttle program and government regulations that make it difficult for NASA to transfer excess facilities to other partners. During a visit to the Stennis Space Center, members heard about the successful "federal city" run by NASA that includes other government agencies such as the U.S. Navy and NOAA, as well as industry partners, that make use of that center's unique characteristics.

During its visits to the NASA centers and JPL, the committee heard that NASA's center leadership desires more flexibility in general to manage their facilities. The committee determined that two particular areas where flexibility can be improved are particularly relevant:

Personnel flexibility. NASA is restricted by law from performing reductions-in-force (RIFs). The prohibition is currently in the 2010 NASA Authorization Act, which expires at the end of FY2013. Congress could act before then (for instance, in an appropriations act) to repeal that language—or could omit the language from new authorization and new appropriations acts. In addition, NASA could be given the ability to convert civil service positions to contractor positions in select instances.

Infrastructure flexibility. The General Services Administration (GSA) imposes restrictions on government agencies charging less than fair market value for facilities, making it difficult for NASA to dispose of facilities it no longer needs. Easing such restrictions for NASA could save the government money by not having to maintain or demolish buildings no longer required by NASA. In addition, current regulations require that disposed property first be offered to state and local governments, a requirement that could slow down or hinder the ability to find private users. If NASA were given more authority to manage its infrastructure instead of leaving this process to GSA, the agency could take better advantage of opportunities in the private sector.

The committee recognizes that personnel and infrastructure restrictions have been imposed upon NASA, as well as the federal government in general, for many valid reasons. For example, there are restrictions on how federal facilities can be disposed of in order to prevent the government from undercutting local real estate markets. However, in these two specific areas the committee was informed that some positive changes are either underway or being evaluated and they are good examples of possible solutions to challenges that NASA faces in personnel and facility management. Naturally, any changes would require careful consideration and evaluation by the legislative and executive branches, but they demonstrate that not all solutions require additional money, and legislative and policy changes can play an important role as well.

Currently, NASA's complex of centers operate quasi-independently rather than as an integrated capability. This has led to competition between centers, duplicative and sub-critical development efforts, and program assignments that are best described as counter-intuitive (such as experimental and development work at centers with no expertise in those areas). Managing the centers as a complex (much the way DOE's Office of Science appears to run their 10 laboratories) would generate efficiencies and lead to more coordinated capabilities for supporting the agency's strategic goals and objectives. The key to doing so is strong oversight, thoughtful coordination, and strategic management. Examples of things that can be done are:

Identifying lead and supporting laboratories for key capabilities;
Creating national user facilities where appropriate;

Eliminating duplicative, sub-critical efforts; and
Diminishing unproductive inter-center competition for resources.

The *2011 NASA Strategic Plan* states that master planning allows NASA "to perform cross-center assessments to examine further opportunities for consolidation of capabilities," but the extent of NASA-wide efforts to manage its facilities remains unclear. Likewise, NASA's various missions areas are not clearly linked across the whole agency in a way that projects a unified organization. If NASA had well established linkages among its missions, that would help establish its strategic direction more clearly.

Finding: NASA officials lack flexibility in how to manage the agency in terms of personnel and facilities, a contributing factor to the mismatch between budget and mission.

Conclusion: The NASA field centers do not appear to be managed as an integrated resource to support the agency and its strategic goals and objectives.

Conclusion: Legislative and regulatory limitations on NASA's freedom to manage its workforce and infrastructure constrain the flexibility that a large organization needs to grow or shrink specific scientific, engineering, and technical areas in response to evolving goals and budget realities.

The committee recognizes that it lacks the capability and time to conduct the detailed supporting analysis and make specific recommendations for changes in the current NASA infrastructure. However, the committee offers a suggested path forward for NASA to follow, in close collaboration with the White House and Congress.

Recommendation: With respect to NASA centers:

The administration and Congress should adopt regulatory and legislative reforms that would enable NASA to improve the flexibility of the management of its centers.
NASA should transform its network of field centers into an integrated system that supports its strategic plan and communications strategy and advances its strategic goals and objectives.

NASA may consider commissioning an independent report from an organization with expertise in how government agencies are organized, such as the National Academy of Public Administration. As already noted, managing NASA's infrastructure is a particular challenge. Some facilities that are not needed in the near-term may be essential several years down the road. Other facilities provide unique national capabilities but are woefully underutilized by current and planned NASA programs. Declining budgets have also produced $2.55 billion in deferred maintenance (in FY2010) that threatens to erode capabilities and reduce the attractiveness of some NASA facilities to third-party users who would have to pay to restore or upgrade a facility before they can use it (Whitlow, 2011). Even within NASA, it is difficult to fund infrastructure maintenance and upgrades using program funds rather than overhead accounts when programs are themselves underfunded. In addition, federal requirements regarding assessment of facility market value impede some options for transferring facilities to other organizations who may be in a better fiscal situation to maintain and use selected facilities.

As noted, making substantial changes to NASA's organization will require support and direction from the administration and Congress.

COMMUNICATING THE VISION

Public interest in space does not equal public support. For example, the public supports the space program in general, but that support is thin when the billion-dollar cost of major NASA programs is revealed and/or when surveys ask the public to prioritize NASA activities with other government functions such as national defense, education, public health, and so on. Even during the Apollo era (see Figure 2.7), public support for that program exceeded 50 percent only when Apollo 11 landed on the Moon. Public support may be very thin for a human mission to Mars, given that it will be very expensive.

During the course of this study, the committee heard from a strategic communications expert on NASA's communications efforts, spoke to NASA public affairs officials at several centers, and also reviewed a 2010 Space Studies Board workshop on this subject. NASA has an exciting story to tell with interesting visuals. But like all government agencies, it is limited by statute from engaging in self-promotion in order to advance its own budgetary and policy interests.

NASA social media and outreach efforts have won awards such as the Space Foundation's Douglas S. Morrow Public Outreach Award (2012) and two Shorty Awards for NASA's use of Twitter (2009, 2012). Also, despite these awards, much of the public remains very poorly informed about the state of NASA in the post-shuttle world, perhaps because the shutdown of the space shuttle program was such big news in the mainstream media, and perhaps because NASA lacks a clear and easily articulated strategic direction. A two-way dialogue (such as public forums) would enable NASA to better understand public perceptions about NASA (so that misperceptions could be corrected) and perhaps foster greater public understanding of and support for planned future missions.

Newsworthy events are typically required for NASA (or any organization) to capture the public's attention, and NASA has been very effective at communicating the excitement associated with specific events. The public awareness effort for the landing of the Curiosity rover on Mars is an excellent recent example of what NASA can do when it has an exciting and clearly defined mission milestone to publicize. It is much more difficult to establish and maintain a sustained level of communication for programs that span many years to decades, but it can be done. For example, NASA announced in 2004 that it would not undertake an additional servicing mission to the Hubble Space Telescope. In response, there was a public outcry—and this outcry was a testament to the effectiveness of NASA's long-term efforts to publicize Hubble as a scientific tool of continuing importance.

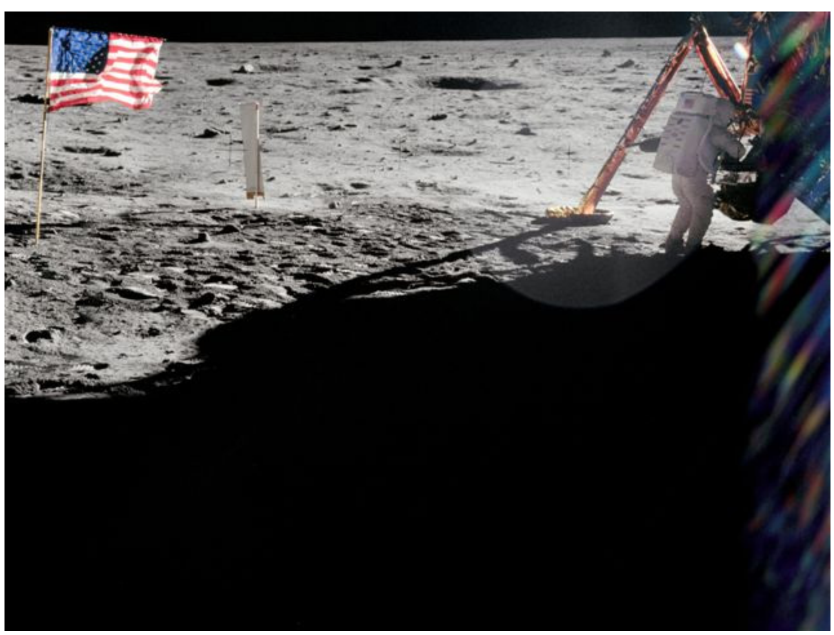

FIGURE 2.7 Neil Armstrong at work near the Lunar Module Eagle. SOURCE: NASA.

Potential elements of a communications strategy for long-term programs might include more "background" efforts that develop the NASA brand. Examples could include undergraduate and graduate fellowships, K-12 education programs, and so on, that are focused on building a workforce that is conscious of the NASA mission. Ultimately, however, the problem that NASA has in communicating its vision is less about the method of communication and more about the lack of a consistent message itself.

CONCLUDING REMARKS

Throughout its storied history, NASA has often assumed—not always deliberately—a flagship role for the United States, demonstrating U.S. technological, scientific, and innovative capabilities in space and aeronautics on the world stage. As discussed throughout this report, NASA is now an agency at a transitional point. The agency faces challenges in nearly all of its primary endeavors—human spaceflight, Earth and space science, and aeronautics—and these challenges largely stem from a lack of consensus on the scope of NASA's broad missions for the nation's future. While human spaceflight has been the most visible of NASA's accomplishments over many decades, there is no consensus on the next destination for humans beyond LEO, and thus on the required technological developments for launch systems, spacecraft, and related technologies. Beyond human spaceflight and operations, robotic space exploration, Earth and space science, and aeronautics all contribute in important ways to the nation's science and technology advancement, but the available funding for support of all of these mission areas will likely be inadequate for the foreseeable future. The committee finds that a clear consensus for the agency's broad mission, and a carefully crafted, ambitious, yet technically realistic set of strategic priorities will be essential for NASA to remain the engine of discovery of which the United States will continue to be justifiably proud.

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Appendixes

A
Statement of Task

The National Research Council will appoint an ad hoc committee to assess whether the strategic direction of the National Aeronautics and Space Administration, as defined by the 2011 NASA strategic plan, remains viable and whether the agency's activities and organization efficiently and effectively support that direction in light of the potential for constrained budgets for the foreseeable future. In particular the committee will:

1. Consider the strategic direction of the agency as set forth most recently in 2011 NASA Strategic Plan and other relevant statements of space policy issued by the President of the United States.
2. Consider the goals for the agency set forth in the National Aeronautics and Space Act of 1958 (as amended) and the National Aeronautics and Space Administration Authorization Acts of 2005, 2008 and 2010.
3. Consider previous studies and reports relevant to this task.
4. Assess the relevance of NASA's strategic direction and goals to achieving national priorities.
5. Assess the viability of NASA's strategic direction and goals in the context of current budget expectations and stated programmatic priorities for the agency.
6. Discuss the appropriateness of the budgetary balance between NASA's various programs;
7. Examine NASA's organizational structure and identify changes that could improve the efficiency and effectiveness of the Agency's mission activities; and
8. Recommend how NASA could establish and effectively communicate a common, unifying vision for NASA's strategic direction that encompasses NASA's varied missions.

Any recommendations made by the committee will be predicated on the assumption that NASA's out-year budget profile will be constrained due to continuing deficit reduction.

B
Committee Meetings and Site Visits

Meeting 1	May 1-2, 2012	Washington, DC
Glenn Research Center - Site Visit	June 11, 2012	Cleveland, OH
Jet Propulsion Laboratory - Site Visit	June 22, 2012	Pasadena, CA
Meeting 2	June 25-27, 2012	Washington, DC
Marshall Space Flight Center - Site Visit	June 28, 2012	Huntsville, AL
Ames Research Center - Site Visit	July 9, 2012	Moffett Field, CA
Dryden Flight Research Center - Site Visit	July 13, 2012	Dryden, CA
Langley Research Center - Site Visit	July 19, 2012	Hampton, VA
Johnson Space Center - Site Visit	July 20, 2012	Houston, TX
Kennedy Space Center - Site Visit	July 24, 2012	Kennedy, FL
Meeting 3	July 26-27, 2012	Washington, DC
Meeting 4	August 6-7, 2012	Irvine, CA
Goddard Space Flight Center - Site Visit	August 17, 2012	Greenbelt, MD
Stennis Space Center - Site Visit	August 22, 2012	Stennis, MS
Meeting 5	September 20-21, 2012	Los Angeles, CA

C
Select Key Reports Concerning NASA's Strategic Direction

1986 *Pioneering the Space Frontier: The Report of the National Commission on Space.* National Commission on Space. Bantam Books, New York. (Paine Report)

This report emphasized a few key themes:

> The new scientific knowledge that space exploration will produce about the Universe, the Solar System, our planet and, indeed, the origin and destiny of life.
>
> The major technology advances that will be pulled through to strengthen 21st-century America's civilian economy and national security;
>
> The leadership that the United States should continue to provide in the development of critical technologies, and in building a Highway to Space and Bridge between Worlds;
>
> The new opportunities that we can create by opening the space frontier for personal fulfillment, for enterprise, and for human settlement; and
>
> The hopes and dreams inspired by removing terrestrial limits to human aspiration, and the relevance of these hopes and dreams to America's pioneer heritage.
>
> NASA should substantially upgrade its emphasis on long-range spaceflight planning studies. We urge NASA to raise the visibility and organizational stature of planning to ensure that the programs we recommend receive continuing and adequate attention; and that NASA operate on the basis of an annually updated five-year budget plan and a 20-year space plan.

1987 *NASA Leadership and America's Future in Space: A Report to the Administrator.* Sally K. Ride.

> We suggest the outline of one strategy—a strategy of evolution and natural progression. The strategy would begin by increasing our capabilities in transportation and technology—not as goals in themselves, but as the necessary means to achieve our goals in science and exploration. The most critical and immediate needs are related to advanced transportation systems to supplement and complement the Space Shuttle, and advance technology to enable bold mission of the next century.

This report recommended the pursuit of four programs in the next 15-20 years (Mars Rover/Sample Return mission, Mission to Planet Earth, humans on Mars, and an outpost on the Moon) as well as the establishment of the Office of Exploration.

1988 *Towards a New Era in Space: Realigning Policies to a New Reality.* National Research Council. National Academy Press, Washington, D.C. (Stever Report)

> Long-term, durable, and widely accepted goals for the nation in space are essential, both to sort out priorities within the space programs, and also to match the pace and direction of the space program with the larger set of national priorities…These goals, established in consultation with the Congress, would provide the stability and consistency that the space program has lacked, and should be an early priority for your civil space policy.

1989 “Remarks on the 20th Anniversary of the Apollo 11 Moon Landing.” George H.W. Bush.

> I’m proposing a long-range, continuing commitment. First, for the coming decade, for the 1990’s: Space Station Freedom, our critical next step in all our space endeavors. And next, for the new century: Back to the Moon; back to the future. And this time, back to stay. And then a journey into tomorrow, a journey to another planet: a manned mission to Mars.

1990 *Report of the Advisory Committee On the Future of the U.S. Space Program.* (Augustine Commission 1)

> It is recommended that the United States’ future civil space program consist of a balanced set of five principal elements:
>
> A science program, which enjoys highest priority within the civil space program, and is maintained at or above the current fraction of the NASA budget
>
> A Mission to Planet Earth focusing on environmental measurements
>
> A Mission from Planet Earth, with the long-term goal of human exploration of Mars, preceded by a modified Space Station which emphasizes life sciences, an exploration base on the Moon, and robotic precursors to Mars
>
> A significantly expanded technology development activity, closely coupled to space mission objectives, with particular attention devoted to engines
>
> A robust space transportation system.

1991 *America at the Threshold: America’s Space Exploration Initiative.* Report of the Synthesis Group on America’s Space Exploration Initiative. (Stafford Report)

> For the effective implementation of the Space Exploration Initiative:
>
> Establish within NASA a long range strategic plan for the nation’s civil space program, with the Space Exploration Initiative as its centerpiece.

1992 *A Post Cold War Assessment of U.S. Space Policy. A Task Group Report.* Vice President’s Space Policy Advisory Board.

> Proceeding ahead with a well-conceived, successfully executed national space program aimed at concrete objectives that are scientifically, economically, and socially beneficial, and that serve important U.S. interests, is the best way to ensure leadership in space.

2003 *Columbia Accident Investigation Board Report.* Columbia Accident Investigation Board.

> None of the competing long-term visions for space have found support from the nation’s leadership, or indeed among the general public. The U.S. civilian space effort has moved forward for more than 30 years without a guiding vision, and none seems imminent. In the past, this absence of a strategic vision in itself has reflected a policy decision, since there have been many opportunities for national leaders to agree on ambitious goals for space, and none have done so.

2004 *The Vision for Space Exploration.* NP-2004-01-334-HQ. NASA, Washington, D.C.

> The fundamental goal of this vision is to advance U.S. scientific, security, and economic interests through a robust space exploration program. In support of this goal, the United States will:
>
> Implement a sustained and affordable human and robotic program to explore the solar system and beyond;

Extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations;
Develop the innovative technologies, knowledge, and infrastructures both to explore and to support decisions about the destinations for human exploration; and
Promote international and commercial participation in exploration to further U.S. scientific, security, and economic interests.

2005 *A Journey to Inspire, Innovate, and Discover.* President's Commission on Implementation of United States Space Exploration Policy. U.S. Government Printing Office, Washington, D.C. (Aldridge Report)

The space exploration vision must be managed as a significant national priority, a shared commitment of the President, Congress, and the American people.

NASA's relationship to the private sector, its organizational structure, business culture, and management processes—all largely inherited from the Apollo era—must be decisively transformed to implement the new, multi-decadal space exploration vision.

Recommended the establishment of a permanent Space Exploration Steering Council.

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

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, returning humans to the Moon, maintaining vigorous space and Earth science and microgravity life and physical sciences programs, and sustaining capabilities in aeronautical research.

Both the executive and the legislative branches of the federal government need to seriously examine the mismatch between the tasks assigned to NASA and the resources that the agency has been provided to accomplish them and should identify actions that will make the agency's portfolio of responsibilities sustainable.

2008 National Aeronautics and Space Administration Authorization Act of 2008.

NASA is and should remain a multi-mission agency with a balanced and robust set of core missions in science, aeronautics, and human space flight and exploration.

Developing United States human space flight capabilities to allow independent American access to the International Space Station, and to explore beyond low Earth orbit, is a strategically important national imperative, and all prudent steps should thus be taken to bring the Orion Crew Exploration Vehicle and Ares I Crew Launch Vehicle to full operational capability as soon as possible and to ensure the effective development of a United States heavy-lift launch capability for missions beyond low Earth orbit.

2009 *America's Future in Space: Aligning the Civil Space Program with National Needs.* National Research Council. The National Academies Press, Washington, D.C. (Lyles Report)

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.

The following recommendations focused on climate and environmental monitoring, scientific inquiry, advanced space technology, international cooperation, human spaceflight, and organizing to meet national needs.

On 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.

2009. *Seeking a Human Spaceflight Program Worthy of a Great Nation*. Review of U.S. Human Spaceflight Plans Committee. (Augustine Commission 2)

> The Committee developed five alternatives for the Human Spaceflight Program. It found:
>
> Human exploration beyond low-Earth orbit is not viable under the FY 2010 budget guideline.
>
> Meaningful human exploration is possible under a less constrained budget, increasing annual expenditures by approximately $3 billion in real purchasing power above the FY 2010 guidance.
>
> Funding at the increased level would allow either an exploration program to explore the Moon First or one that follows the Flexible Path. Either could produce significant results in a reasonable time frame.

2010. National Aeronautics and Space Administration Authorization Act of 2010.

> While commercial transportation systems have the promise to contribute valuable services, it is in the United States national interest to maintain a government operated space transportation system for crew and cargo delivery to space.
>
> The United States must develop, as rapidly as possible, replacement vehicles capable of providing both human and cargo launch capability to low-Earth orbit and to destinations beyond low-Earth orbit.

2010. National Space Policy of the United States of America. June 28.

> The United States will pursue the following goals in its national space programs:
>
> Energize competitive domestic industries . . .
> Expand international cooperation . . .
> Strengthen stability in space . . .
> Increase assurance and resilience of mission-essential functions . . .
> Pursue human and robotic initiatives . . .
> Improve space-based Earth and solar observation . . .

2010. Departments of Commerce and Justice, and Science, and Related Agencies Appropriations Bill for FY 2011.

> The Committee believes this bill represents a solid compromise for human spaceflight that reaches beyond low Earth orbit with affordable vehicles; makes key investments in the burgeoning commercial launch industry that is already poised to bring cargo to the ISS; before the Shuttle is retired in 2011, authorizes one additional Shuttle flight, if determined to be safe, to preposition supplies at the ISS; and revitalizes NASA technology programs. The Committee invests in a new heavy-lift rocket to be built by 2017, along with the Orion capsule to carry astronauts, so NASA can again send humans on new journeys of discovery.

D
Committee and Staff Biographical Information

ALBERT CARNESALE, *Chair,* is chancellor emeritus and professor at the University of California, Los Angeles (UCLA). He was chancellor of the university from 1997 through 2006 and now serves as a professor of public policy and of mechanical and aerospace engineering. Prior to joining UCLA, Dr. Carnesale served at Harvard University for 23 years as the Lucius N. Littauer Professor of Public Policy and Administration, dean of the John F. Kennedy School of Government, and provost of the university. He also previously served in both government and industry. His research and teaching focus on public policy issues having substantial scientific and technological dimensions. Dr. Carnesale is the author or co-author of six books and more than 100 articles on a wide range of subjects, including national security strategy, arms control, nuclear proliferation, the effects of technological change on foreign and defense policy, domestic and international energy issues, and higher education. He is a member of the National Academy of Engineering. Dr. Carnesale serves on the Mission Committees of the Lawrence Livermore National Laboratory and the Los Alamos National Laboratory, the board of directors of Harvard University's Belfer Center for Science and International Affairs, and the advisory board of the RAND Corporation's Center for Global Risk and Security. He is also a fellow of the American Academy of Arts and Sciences and the American Association for the Advancement of Science, and he is a member of the Council on Foreign Relations. Dr. Carnesale holds a B.M.E from the Cooper Union for the Advancement of Science and Art, an M.S. in mechanical engineering from Drexel University, and a Ph.D. in nuclear engineering from North Carolina State University. He has served as a member of the Secretary of Energy's Blue Ribbon Commission on America's Nuclear Future. He has previously served as chair of the National Research Council (NRC) Committee on Conventional Prompt Global Strike Capability, the Committee on Sustaining and Improving the Nation's Nuclear Forensics, and the Committee on America's Climate Choices.

RONALD M. SEGA is vice president and enterprise executive for energy and the environment for Colorado State University (CSU) and Ohio State University (OSU). At CSU, Dr. Sega is also the Woodward Professor of Systems Engineering, the director of graduate programs in systems engineering, and serves as chair of the Sustainability, Energy, and Environment Advisory Committee. At OSU he is also the chair of the President's and Provost's Council on Sustainability. Dr. Sega most recently was the under secretary of the Air Force where he served as the Department of Defense (DOD) Executive Agent for Space and led the Air Force team that won the Overall Presidential Award for Leadership in Federal Energy Management for 2006. From 2001-2005, he was the director of Defense Research and Engineering, the chief technology officer for DOD. He retired from the Air Force Reserve as a major general in the position of reserve assistant to the chairman of the Joint Chiefs of Staff after 31 years in the Air Force, having served in various assignments at Air Force Space Command and as a pilot. A former astronaut, Dr. Sega flew aboard the space shuttles *Discovery* and *Atlantis*. Dr. Sega has also been a faculty member in the College of Engineering and Applied Science at University of Colorado, Colorado Springs, and served as dean from 1996-2001. He holds a B.S. in mathematics and physics from the U.S. Air Force Academy in Colorado Springs, an M.S. in physics from OSU, and a Ph.D. in electrical engineering from the University of Colorado. He is currently a member of the NRC Division Committee on Engineering and Physical Sciences and has previously served as chair of the Committee on Cost Growth in NASA Earth and Space Science Missions and is an ex officio member of the Government-University-Industry Research Roundtable.

MARK R. ABBOTT is dean of the College of Earth, Ocean and Atmospheric Sciences at Oregon State University, Corvallis. His research focuses on the interaction of biological and physical processes in the upper ocean, remote sensing of ocean color and sea surface temperature, phytoplankton fluorescence, and length and time scales of phytoplankton variability. He deployed the first array of bio-optical moorings in the Southern Ocean as part of the U.S. Joint Global Ocean Flux Study (JGOFS). Dr. Abbott chaired the U.S. JGOFS Science Steering Committee and was a member of the MODIS and SeaWiFS science teams. He is currently a member of the board of trustees for the Consortium for Ocean Leadership and a consultant to the National Science Board. Dr. Abbott earned a B.S. in conservation of natural resources at the University of California, Berkeley, and a Ph.D. in ecology from the University of California, Davis. Dr. Abbott has also served as the chair of the SSB's Committee on Earth Studies. Other prior NRC service includes the Committee on Indicators for Understanding Global Climate Change, the Committee on the Role and Scope of Mission-Enabling Activities in NASA's Space and Earth Sciences Missions, and the Panel on Land-Use Change, Ecosystem Dynamics, and Biodiversity for the 2007 decadal survey on Earth science and applications from space. Dr. Abbott was a member of the NRC's Committee on an Assessment of NASA's Earth Science Program, which carried out a mid-decade assessment of the implementation of the Earth science and applications from space decadal survey. He is presently a member of the Space Studies Board and chairs the Committee on Earth Science and Applications from Space.

JACQUES E. BLAMONT is an advisor to the president of the French national space agency, Centre National d'Etudes Spatiales (CNES). Dr. Blamont previously served as CNES's first scientific and technical director, as chief scientist, and as advisor to the director general. In addition to his career at CNES, he was a professor at the University of Paris. During that period, Dr. Blamont was the director of the largest space laboratory in France, CNRS's Service d'Aéronomie. He was also a distinguished visiting scientist at the Jet Propulsion Laboratory (JPL) and a professor at the California Institute of Technology. Dr. Blamont still teaches at the Ecole de Guerre (War College) of the French Ministry of Defense. Involved in atmospheric research, he discovered the turbopause, the interstellar wind, and the hydrogen halo of comets. He is the author of the first measurements of atmospheric temperature from an altitude of 100 to 500 km, he made the first determination of Einstein's general relativity red shift on the Sun, and he conceived and led the French-Soviet mission of balloons in Venus's atmosphere. Dr. Blamont was a member of the science groups of the NASA missions Voyager and Pioneer-Venus and the Soviet Union's missions Vega and Phobos. He was a major contributor to the lunar Clementine mission led by the U.S. DOD, for which he developed an image data compression system later used in Cassini-Huygens, Mars Express, Venus Express, and the French missions SPOT-5 and Helios II. He is a member of the French Academie des Sciences and the National Academy of Sciences and is a foreign associate of the American Philosophical Society and of the Indian Natural Academy of Sciences. Among his honors are the NASA Medal for Exceptional Scientific Achievement (1972), the NASA Distinguished Service Medal (2000), the Gagarine Medal and Order of People's Friendship of the USSR, the Guggenheim Medal and the Von Karman Medal, and the COSPAR Science Award (2004). Dr. Blamont has published five books, more than 200 scientific papers, and hundreds of papers on various science and policy subjects. He holds a D.Sc. and a B.S in physics from Ecole Normale Supérieure. Dr. Blamont was previously a member of the NRC Planetary and Lunar Exploration Task Group.

JOHN C. BROCK is an independent aerospace technology consultant. He is recently retired from Northrop Grumman Aerospace Systems, where he was director of technology strategy and planning. Before its acquisition by Northrop Grumman, Dr. Brock was chief technologist of TRW's Space and Technology sector and a senior scientist with expertise in optoelectronics, high energy lasers, space systems and technologies, and technology planning and road mapping. Prior to joining TRW in 1980, Dr. Brock was a NASA-JPL NRC fellow studying atmospheric photochemistry. Dr. Brock has served as member of the Air Force Scientific Advisory Board and chaired the board's study on the Operational Utility of Small Satellites. He also has served on the Defense Science Board Advisory Group on Electron

Devices, the Air Force Tactical Applications Center Space Advisory Group, and the advisory boards of numerous university optoelectronic Centers of Excellence. He is an associate fellow of the American Institute of Aeronautics and Astronautics (AIAA), received the Air Force Exemplary Civilian Service Medal in 2008, and was a TRW/NGC senior technical fellow from 1995 until his retirement. Dr. Brock earned a B.S. in chemistry from the University of Washington and his Ph.D. in chemical physics from the University of California, Berkeley.

ROBERT L. CRIPPEN is retired from Thiokol Propulsion Group, Brigham City, Utah, where he served as president. He is also a retired captain of the U.S. Navy. He joined NASA as an astronaut in 1969 and went on to serve as a member of the astronaut support crew for three Skylab missions, as well as the Apollo-Soyuz Test Project mission, which was completed in 1975. He served as pilot on STS-1 (1981), and was the spacecraft commander on STS-7 (1983), STS-41C (1984) and STS-41G (1984). From 1986-1989, he was deputy director for shuttle operations at Kennedy Space Center (KSC), where he was responsible for final shuttle preparation and mission execution. He also served as director for the space shuttle at NASA Headquarters from 1990 until he was named KSC director in 1992. In his headquarters post, Captain Crippen presided over the overall shuttle program requirements and performance, and total program control. As KSC Center director, he managed the processing, launch, and recovery of space shuttle missions. He next served as vice president of Training Simulation Systems at Lockheed Martin Information Systems. In 1996, Captain Crippen was named president of the Thiokol Propulsion Group. He retired in 2001. He received his B.S. in aerospace engineering University of Texas, Austin. He is a member of the National Academy of Engineering and previously served on the Aeronautics and Space Engineering Board.

JOSEPH S. HEZIR is the co-founder and managing partner of the EOP Group, Inc., a consulting firm that specializes in federal government regulatory strategy development and budget policy. He previously served 18 years in the White House Office of Management and Budget in positions of increasing responsibility, serving for 6 years as deputy associate director for energy and science. He has also served on a number of advisory bodies, including the NASA Advisory Council and the Metropolitan Area Board of Directors for the Red Cross. From Carnegie Mellon University, Mr. Hezir earned a B.S. in chemical engineering and an M.S. from the Heinz School of Public Policy. He has served on numerous NRC committees, including the Committee on EPP2010: Elementary Particle Physics in the 21st Century, the Committee on Burning Plasma Assessment and the Committee on Cost of and Payment for Animal Research; he is currently a member on the Board on Physics and Astronomy.

ANN R. KARAGOZIAN is a professor in the Department of Mechanical and Aerospace Engineering at the UCLA. Her research interests are in fluid mechanics, propulsion, and combustion, with applications to high-efficiency energy generation and aerospace propulsion systems. Dr. Karagozian served as the vice chair of the Air Force Scientific Advisory Board (SAB), and twice received the Air Force Decoration for Exceptional Civilian Service. She chaired a wide-ranging study for the SAB on the Future of Launch Vehicles for the U.S. Air Force and previously chaired studies for the SAB on Air Vehicle Fuel Efficiency and Persistence at Near Space Altitudes. She also served on the NASA Aeronautics Advisory Committee. Dr. Karagozian is the immediate past chair of the American Physical Society (APS) Division of Fluid Dynamics and also is immediate past chair of the UCLA Academic Senate, representing 3,500 UCLA faculty. She is a fellow of both AIAA and APS. She received her B.S. in engineering, summa cum laude, from UCLA and her M.S. and Ph.D. degrees in mechanical engineering from the California Institute of Technology. Dr. Karagozian is currently a member-at-large of the NRC U.S. National Committee on Theoretical and Applied Mechanics and has previously served as a member of the Committee to Identify Potential Breakthrough Technologies and Assess Long-Term R&D Goals in Aeronautics and Space Transportation Technology, the Panel on Platforms, and the Committee on Space Facilities.

MARK J. LEWIS is the director of the Institute for Defense Analyses Science and Technology Policy Institute and a former Willis Young, Jr., Professor and chair of the Department of Aerospace Engineering at the University of Maryland. From 2004-2008, he served as the chief scientist of the U.S. Air Force. He is also the past president of AIAA. Dr. Lewis has been teaching and conducting basic and applied research in the fields of hypersonic aerodynamics, advanced propulsion, and space vehicle design and optimization. His work has spanned the aerospace flight spectrum from the analysis of conventional jet engines to entry into planetary atmospheres at hypervelocity speeds, with a specialty in the integration of high-speed engines with highly efficient airframes. Dr. Lewis is the author of more than 290 technical publications, and he has been adviser to more than 60 graduate students. A recipient of both the DOD Meritorious Civilian Service Award and Exceptional Civilian Service Award, Dr. Lewis received the IECEC/AIAA Lifetime Achievement Award and was named an Aviation Week and Space Technology Laureate in 2007. He is a fellow of the American Society of Mechanical Engineers, a fellow of AIAA, and a president's fellow of the Royal Aeronautical Society. Dr. Lewis received a B.S. in aeronautics and astronautics and in Earth and planetary science and M.S. and Ph.D. degrees in aeronautics and astronautics at the Massachusetts Institute of Technology. He is currently a member of the NRC Air Force Studies Board and has previously served as a member of Panel B: Robotic Access and Human Planetary Landing Systems and the Panel to Review Air Force Office of Scientific Research Proposals in Fluids.

MARCIA S. SMITH is the president of Space and Technology Policy Group, LLC, and founder and editor of SpacePolicyOnline.com. Previously, she was the director of the Space Studies Board and the Aeronautics and Space Engineering Board of the NRC. For the prior 31 years, she was a space and technology policy specialist for the Congressional Research Service (CRS), a department of the Library of Congress that provides objective and non-partisan research and analysis exclusively for members and committees of Congress. She took a leave of absence from CRS to serve as executive director of the congressionally chartered, presidentially appointed National Commission on Space. Chaired by (the late) former NASA Administrator Thomas O. Paine, the commission laid out a 50-year plan (through 2035) for the civilian space program in its report *Pioneering the Space Frontier*. She is the author of more than 200 reports and articles on military, civil, and commercial space programs; telecommunications (including the technology policy aspects of Internet privacy and other Internet issues); and nuclear energy. Ms. Smith is the North American editor for the quarterly journal *Space Policy*. Among her many professional affiliations, she is a fellow of AIAA and has served on many of its committees and as an AIAA distinguished lecturer. She is a fellow of the American Astronautical Society for which she is currently its vice president of public policy; in the past she has served as president and in other official capacities and received its John F. Kennedy Award in 2006. She is a founder, past president, and emeritus member of Women in Aerospace and received its Lifetime Achievement Award in 2003. She is member and past trustee of the International Academy of Astronautics; a member and past vice president of the International Institute of Space Law; and a life member of the New York Academy of Sciences, the Washington Academy of Sciences, and Sigma Xi. Ms. Smith earned an A.B. in political science from Syracuse University. She has previously served as a member of the NRC Committee on Human Exploration.

MICHAEL S. TURNER is the Rauner Distinguished Service Professor and director of the Kavli Institute for Cosmological Physics at the University of Chicago. He is also president-elect of APS. He has previously served as chief scientist at Argonne National Laboratory, as assistant director for the Mathematical and Physical Sciences at the National Science Foundation, and as president of the Aspen Center for Physics. Dr. Turner helped to pioneer the interdisciplinary field of particle astrophysics and cosmology. His scholarly contributions include predicting cosmic acceleration and coining the term "dark energy," and showing how during cosmic inflation quantum fluctuations evolved into the seed perturbations for galaxies. His honors include the Warner Prize of the American Astronomical Society (AAS), the Lilienfeld Prize of the APS, the Klopsted Award of the American Association of Physics Teachers, the Heineman Prize (with Kolb) of the AAS and American Institute of Physics, and the 2011

Darwin Lecture of the Royal Astronomical Society. He is a fellow of the APS, American Academy of Arts and Sciences, and the American Association for the Advancement of Science. Dr. Turner received his B.S. from California Institute of Technology, his M.S. and Ph.D. degrees from Stanford University, all in physics, and an honorary doctorate from Michigan State University. He is a member of the National Academy of Sciences and of its Governing Board. He currently serves as a member of the NRC Board on Physics and Astronomy, the Committee on Science, Engineering, and Public Policy, and has previously served on the Committee on Decadal Survey on Astronomy and Astrophysics 2010.

WARREN M. WASHINGTON is a senior scientist and former head of the Climate Change Research Section and director of the Climate and Global Dynamics Division at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado. His expertise is in atmospheric and climate research. He has engaged in research for more than 40 years, and he has given advice, testimony, and lectures on global climate change. Dr. Washington has been a member the President's National Advisory Committee on Oceans and Atmosphere and has had presidential appointments under the Carter, Reagan, Clinton, and Bush administrations. More recently, he served on the National Science Board as a member and as chair. He has more than 150 publications and co-authored with Claire Parkinson a book that is considered a standard reference on climate modeling, *An Introduction to Three-Dimensional Climate Modeling,* and an autobiography, *Odyssey in Climate Modeling, Global Warming, and Advising Five Presidents*. Dr. Washington has many awards, including being a member of the National Academy of Engineering, the American Meteorological Society (former president), the American Philosophical Society, and the American Academy of Arts and Sciences. Members of his group at NCAR shared in the 2007 Nobel Peace Prize as significant contributors to the Inter-governmental Panel of Climate Change (IPCC) Assessment. Dr. Washington has honorary degrees from OSU and Bates College. He has been the principal investigator on the Department of Energy (DOE) INCITE proposal for the Climate End Station, which coordinates computer time for development of state-of-art climate models and the use of such models for present and future climate change studies. He is also principal investigator for the University for Atmospheric Research and DOE cooperative agreement that carried out climate research. In November 2010, he was awarded the National Medal of Science by President Obama, the nation's highest science award. Dr. Washington earned a B.S. in physics and M.S. in meteorology from Oregon State University and a Ph.D. in meteorology from Pennsylvania State University. He has served on a number of NRC committees, including as a member of the Space Studies Board, the Survey Steering Committee for Earth Science and Applications from Space: A Community Assessment and Strategy for the Future, and is currently serving as chair of the Committee to Advise the U.S. Global Change Research Program.

STAFF

DWAYNE A. DAY, *Study Director,* a senior program officer for the NRC's Aeronautics and Space Engineering Board (ASEB), has a Ph.D. in political science from the George Washington University. Dr. Day joined the NRC as a program officer for the Space Studies Board (SSB). Before this, he served as an investigator for the Columbia Accident Investigation Board, was on the staff of the Congressional Budget Office, and also worked for the Space Policy Institute at the George Washington University. He has held Guggenheim and Verville fellowships and was an associate editor of the German spaceflight magazine *Raumfahrt Concrete,* in addition to writing for such publications as *Novosti Kosmonavtiki* (Russia), *Spaceflight,* and *Space Chronicle* (United Kingdom). He has served as study director for several NRC reports, including *Space Radiation Hazards and the Vision for Space Exploration* (2006), *Grading NASA's Solar System Exploration Program: A Midterm Review* (2008), and *Opening New Frontiers in Space: Choices for the Next New Frontiers Announcement of Opportunity* (2008).

ALAN C. ANGLEMAN has been a senior program officer for ASEB since 1993, directing studies on the modernization of the U.S. air transportation system, system engineering and design systems, aviation weather systems, aircraft certification standards and procedures, commercial supersonic aircraft, the safety of space launch systems, radioisotope power systems, cost growth of NASA Earth and space science missions, and other aspects of aeronautics and space research and technology. Previously, Mr. Angleman worked for consulting firms in the Washington area providing engineering support services to the DOD and NASA Headquarters. His professional career began with the U.S. Navy, where he served for 9 years as a nuclear-trained submarine officer. He has a B.S. in engineering physics from the U.S. Naval Academy and an M.S. in applied physics from the Johns Hopkins University.

DAVID H. SMITH joined the Space Studies Board (SSB) in 1991. He is the senior staff officer and study director for a variety of NRC activities in planetary science, astrobiology, and astrophysics. He also organizes the SSB's Lloyd V. Berkner Summer Policy Internship program and supervises most, if not all, of the interns. He received a B.Sc. in mathematical physics from the University of Liverpool in 1976, completed Part III of the Mathematics Tripos at Cambridge University in 1977, and earned a D.Phil. in theoretical astrophysics from Sussex University in 1981. Following a postdoctoral fellowship at Queen Mary College University of London (1980-1982), he held the position of associate editor and, later, technical editor of *Sky and Telescope*. Immediately prior to joining the staff of the SSB, Dr. Smith was a Knight Science Journalism Fellow at the Massachusetts Institute of Technology.

CATHERINE A. GRUBER, editor, 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 also worked as an outreach assistant for the 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.

AMANDA R.THIBAULT, research associate, joined the ASEB in 2011. Ms. Thibault is a graduate of Creighton University, where she earned her B.S. in atmospheric science in 2008. From there she went on to Texas Tech University, where she studied lightning trends in tornadic and non-tornadic supercell thunderstorms and worked as a teaching and research assistant. She participated in the VORTEX 2 field project from 2009 to 2010 and graduated with an M.S. in atmospheric science from Texas Tech in August 2010. She is a member of the American Meteorological Society.

ANDREA M. REBHOLZ, program associate, joined the ASEB in 2009. She began her career at the National Academies in October 2005 as a senior program assistant for the Institute of Medicine's Forum on Drug Discovery, Development, and Translation. Prior to the Academies, she worked in the communications department of a D.C.-based think tank. Ms. Rebholz graduated from George Mason University's New Century College in 2003 with a B.A. in integrative studies-event management and has more than 8 years of experience in event planning.

LINDA WALKER has been with the National Academies since 2007. Before her assignment with the SSB, she was on assignment with the National Academies Press. Prior to her working at the National Academies, she was with the Association for Healthcare Philanthropy in Falls Church, Virginia. Ms. Walker has 28 years of administrative experience.

DANIELLE PISKORZ, an SSB Lloyd V. Berkner space policy intern, recently graduated from the Massachusetts Institute of Technology with a degree in physics and a minor in applied international studies. She has done various research projects at L'Institut d'Astrophysique de Paris, Los Alamos National Laboratories, and the Jet Propulsion Laboratory and spent her junior year studying at the University of Cambridge. Ms. Piskorz plans to begin her graduate studies in Fall 2012 in geophysics.

MICHAEL H. MOLONEY is the director of the SSB and the ASEB at the NRC. Since joining the NRC in 2001, Dr. Moloney has served as a study director at the National Materials Advisory Board, the Board on Physics and Astronomy (BPA), the Board on Manufacturing and Engineering Design, and the Center for Economic, Governance, and International Studies. Before joining the SSB and ASEB in April 2010, he was associate director of the BPA and study director for the Astro2010 decadal survey for astronomy and astrophysics. In addition to his professional experience at the NRC, Dr. Moloney has more than 7 years' experience as a foreign-service officer for the Irish government and served in that capacity at the Embassy of Ireland in Washington, D.C., the Mission of Ireland to the United Nations in New York, and the Department of Foreign Affairs in Dublin, Ireland. A physicist, Dr. Moloney did his graduate Ph.D. work at Trinity College Dublin in Ireland. He received his undergraduate degree in experimental physics at University College Dublin, where he was awarded the Nevin Medal for Physics.