Building a Better NASA Workforce: Meeting the Workforce Needs for the National Vision for Space Exploration

Committee on Meeting the Workforce Needs for the National Vision for Space Exploration, National Research Council

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Preface

In January 2004 President George W. Bush announced a new civilian space policy that soon became known as the Vision for Space Exploration (VSE).[1] The VSE has several cornerstones, including retiring the Space Shuttle by 2010, completing the International Space Station, and establishing a broad goal for human exploration of the Moon and Mars. The first steps in the new human exploration phase involve developing a spacecraft for transporting humans into space, developing a lunar lander spacecraft, and building new launch vehicles for both spacecraft. This new space policy poses many challenges for NASA, among them the agency's ability to manage and conduct its programs so as to achieve its major goals within a constrained budget environment. A significant question is whether the agency has a workforce with an effective mix of skills and personnel, or adequate mechanisms for acquiring them.

On September 30, 2005, NASA's Associate Administrator for Program Analysis and Evaluation, Scott Pace, sent a letter to Lennard Fisk, chair of the National Research Council's (NRC's) Space Studies Board (SSB), requesting that the SSB and the Aeronautics and Space Engineering Board (ASEB) help assess the current and future supply of highly skilled U.S. aerospace professionals and identify realistic, actionable solutions to meeting any identified needs (see Appendix A). Formed under the auspices of the SSB and ASEB in late 2005, the NRC Committee on Meeting the Workforce Needs for the National Vision for Space Exploration was asked to study the long-range science and technology workforce needs of NASA and the larger aerospace science and engineering community to achieve the Vision for Space Exploration; identify obstacles to filling those needs; and recommend specific actions for consideration by government, academia, and industry (see Appendix B for the full statement of task). The committee comprised members from the traditional U.S. science and technology triangle of government, academia, and industry as well as members from the emerging entrepreneurial (the so-called "alt-space" or "new space") community and from outside the space community (see Appendix D).

On January 23-25, 2006, the committee held a workshop to identify the important factors affecting NASA's future workforce and its capacity to implement the VSE. The specific goal of the workshop was to engage representatives of government, academia, and industry in discussing the issues to be explored by the committee in preparing its final report and to identify the available data on NASA's workforce. The committee met again on February 22-23, 2006, to gather additional information regarding NASA's analysis of current and future workforce

[1]The Vision for Space Exploration initiative was announced by President George W. Bush on January 14, 2004, and is outlined in *The Vision for Space Exploration*, NP-2004-01-334-HQ, NASA, Washington, D.C., 2004.

competencies and to hear from representatives from the Bureau of Labor Statistics and the aerospace industry. A third committee meeting, on May 8-9, 2006, provided an opportunity for the committee to have further discussions with NASA officials and to interact with representatives from university science and engineering departments and from the American Society for Engineering Education. A fourth meeting was held on September 27-29 to enable the committee to deliberate and write its final report.

In late April 2006 the committee released an interim report, *Issues Affecting the Future of the U.S. Space Science and Engineering Workforce: Interim Report*, which presented the committee's summary of highlights of the January 2006 workshop and provided initial, but incomplete, findings with respect to some aspects of the study charge.[2]

This final report incorporates the findings and recommendations from the interim report, and it presents the committee's final conclusions on all aspects of the study. Tasks 1 and 2 (see Appendix B), which address the demographics of the workforce, are discussed in Chapter 2. Chapter 3 examines NASA's and the committee's analyses of skills that will be needed in the future in NASA and in industry (tasks 3 and 5), and Chapter 5 addresses the roles of and needs in academia (task 4). Chapter 4 responds to Task 6 regarding workforce gaps and obstacles, and it discusses specific actions needed to address a particularly pressing need in NASA and industry for highly skilled systems engineers and program/project managers. Relevant recommendations for actions by the government, industry, and academia accompany the discussions in each of the four main chapters.

[2]National Research Council, *Issues Affecting the Future of the U.S. Space Science and Engineering Workforce: Interim Report*, The National Academies Press, Washington, D.C., 2006. NASA responded to this interim report in a meeting, and written materials and comments presented to the committee were incorporated into this final report.

Acknowledgments

The committee thanks Kathleen Hyland of Johns Hopkins University, who helped prepare the assessment of prior Bureau of Labor Statistics employment projections discussed in Chapter 2, and the Aerospace Industries Association's Space Council, which helped provide the industry perspectives that are also discussed in Chapter 2. The committee also thanks the numerous NASA staff members who provided considerable information about NASA's workforce assessments, plans, and programs.

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

A. Dwight Abbott, Aerospace Corporation (retired),
Aaron Cohen, Texas A&M University (professor emeritus),
Ron Hira, Rochester Institute of Technology,
Martin H. Israel, Washington University, St. Louis,
T.K. Mattingly, U.S. Navy (retired),
Michael Meyer, Georgia Institute of Technology,
Thomas S. Moorman, Jr., U.S. Air Force (retired),
Jeffrey D. Rosendhal, NASA (retired), and
Paula Stephan, Georgia State University.

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 Lester A. Hoel, University of Virginia. Appointed by the National Research Council, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Contents

APPENDIXES

Executive Summary

The Vision for Space Exploration (VSE) announced by President George W. Bush in 2004 sets NASA and the nation on a bold path to return to the Moon and one day put a human on Mars.[1] The long-term endeavor represented by the VSE is, however, subject to the constraints imposed by annual funding. Given that the VSE may take tens of years to implement, a significant issue is whether NASA and the United States will have the workforce needed to achieve that vision. The issues range from short-term concerns about the current workforce's skills for overseeing the development of new spacecraft and launch vehicles for the VSE to long-term issues regarding the training, recruiting, and retaining of scientists and engineers in-house as well as in industry and academia.

Asked to explore science and technology (S&T) workforce needs to achieve the nation's long-term space exploration vision (see Appendix B for the full statement of task), the Committee on Meeting the Workforce Needs for the National Vision for Space Exploration concluded that in the short term, NASA does not possess the requisite in-house personnel with the experience in human spaceflight systems development needed to implement the VSE. But the committee acknowledges that NASA is cognizant of this fact and has taken steps to correct it, primarily by seeking to recruit highly skilled personnel from outside NASA, including persons from industry and retirees.

For the long term, NASA has to ask if it is attracting and developing the talent it will need to execute a mission to return to the Moon, and the agency must identify what it needs to do to attract and develop a world-class workforce to explore other worlds. A major challenge for NASA is reorienting its human spaceflight workforce from the operation of current vehicles to the development of new vehicles at least throughout the next decade, as well as starting operations with new rockets and new spacecraft.

NASA's April 2006 *Workforce Strategy* discussed agency workforce competency trends, identifying an increased need for personnel in five skill areas through 2009.[2] These include 150-200 full-time employees in program/project management, 100-150 in systems engineering and integration engineering, and 200-240 in mission operations—numbers driven primarily by the establishment of the Constellation program.[3] At the time NASA

[1]The Vision for Space Exploration initiative was announced by President George W. Bush on January 14, 2004, and is outlined in *The Vision for Space Exploration*, NP-2004-01-334-HQ, NASA, Washington, D.C., 2004.

[2]NASA, *National Aeronautics and Space Administration Workforce Strategy*, April 2006, pp. 15-16, available at http://nasapeople.nasa.gov/HCM/WorkforceStrategy.pdf.

[3]NASA's Constellation program includes development of the Orion spacecraft, the Ares I and Ares V launch vehicles, and the lunar lander required to return Americans to the Moon. NASA has begun initial development of the Orion and the Ares I, with the goal of conducting the first piloted Orion launch by the middle of the next decade.

established those requirements, the agency had a total of approximately 1650 persons in these categories involved in other projects. The committee concluded that although many of the employees required in the mission operations category could be transitioned from the Space Shuttle program, many of the 250-350 full-time employees needed in the program/project management and systems engineering and integration engineering competencies are unlikely to currently reside in the agency and will have to be acquired from industry. NASA last had substantial in-house involvement in human spaceflight systems engineering in the 1970s, during the design phase of the Space Shuttle program, and the people skilled in human spaceflight are now likely to exist only in industry.

Although human and robotic systems are distinct, they do share many management and engineering process as well as system technical characteristics. Given that the bulk of the development activities over the past 10 years have been in robotic spacecraft, NASA needs to leverage the robotic spacecraft workforce skill development opportunities to meet some of the human spaceflight program development skill needs. *The committee believes that systems engineering methodology and technical skills acquired from complex robotic spacecraft development can serve as an important base for the transition to systems engineering of human spacecraft.*

A problem faced by the committee was a lack of data, as well as differing interpretations of future requirements for certain skills and an absence of information correlating levels of expertise required with the numbers of employees anticipated to be needed. Based on available demographic data, however, the committee concluded that, in the broadest sense, there is no looming national shortage of skilled scientists and engineers to implement the VSE over the long term. For example, the committee saw no evidence of a downturn in the national supply of new talent in aerospace engineering and space sciences. The supply of and the demand for new aerospace workers appear to be relatively well matched at present, as evidenced in part by the fact that salaries in aerospace engineering are not increasing sharply relative to those in other fields.[4] Although the committee acknowledges the difficulties in predicting future demand for particular labor skills, it notes that past predictions of substantially increased demand for aerospace workers have not been borne out in reality. However, the committee also notes that both NASA and the aerospace industry employ engineers from many different fields besides aerospace engineering, such as electrical engineering and mechanical engineering, making a comparison of supply and demand for NASA more complicated than it would at first appear.

Much of the workforce on which NASA has historically relied, and will continue to rely, exists outside the agency: Most of the engineers who work on NASA projects are in industry, and most of the scientists are at universities. Retaining the proper numbers of each component of the broader aerospace workforce poses fundamentally different challenges. For example, engineers in industry generally have to rely less on NASA for the long-term financial stability of their projects than do scientists in universities, who often cannot move to military or commercial projects if NASA's support for their work ends. Science talent might be lost and not readily regained even a few years later if NASA withdraws support for scientific research even for a limited period and scientists leave the field or are unwilling to return to NASA-sponsored work for which funding has proven unstable in the past. Thus, the policies that NASA pursues to sustain the workforce outside the agency will, and must, be different for scientists and engineers.

Furthermore, because NASA represents only a fraction of the overall aerospace workforce, the agency's current workforce and its potential workforce are affected by numerous other government agencies, industry, and academia. In some cases, NASA must compete directly with these organizations for appropriately skilled workers. The committee therefore concluded that some method of coordinating overall strategies concerning aerospace workforce issues between related institutions, such as NASA and the Department of Defense, would be valuable.

The agency also has to address the retention and development of NASA's in-house workforce. NASA's policies for ensuring sufficient in-house talent will possibly diverge from those it pursues for maintaining and accessing the external workforce.

In considering these issues, the committee sought in particular to identify requirements common to both the scientific and the engineering talent needed within as well as from outside the agency. Ultimately, the committee concluded that the salient requirement was the need for junior-level members of the workforce—including current

[4] In contrast, the committee notes that engineering salaries in some areas, such as the petrochemical industry, are increasing rapidly because the supply is not meeting the increased demand.

and potential employees—to gain hands-on experience that would satisfy one of the perennial issues facing the agency: the need for highly skilled program/project managers and systems engineers.

In addition, the committee noted that over approximately the past decade and a half, the average age of NASA's workers has marched steadily upward, and the agency now has a relatively low number of younger workers to assume future leadership roles in NASA as older workers retire. If it does nothing to achieve a better age distribution across its overall internal workforce, NASA will suffer a gap not only in technical leadership, but also in overall technical experience, especially if the development dates for key VSE components slip and highly skilled workers with experience in the Space Shuttle program retire. The committee concluded that if NASA is to avoid a long-term shortage of the required in-house technical expertise in human spaceflight systems and other areas, it will have to adopt a strategy to address potential long-term shortfalls.

Fortunately, NASA does have programs and methods currently available for meeting its workforce needs. These include, but are not limited to, legislative authority to enhance recruitment of workers with the required skills, internal training programs such as the intramural Academy of Program/Project and Engineering Leadership (APPEL; focused primarily on engineers), and extramural programs such as the Graduate Student Researchers Program (GSRP; focused currently on scientists). Although the committee highlights these specific programs, there are also others by which the agency trains current and potential members of its workforce. However, the committee found that many of these programs have atrophied over time and require revitalization and restructuring. In the case of GSRP, for example, NASA sponsors fellowships with award amounts that are significantly smaller than those provided by other government agencies, placing NASA at a competitive disadvantage.[5] The committee also noted with alarm that shortly before it completed its work, NASA headquarters restricted its GSRP for budgetary reasons to accept only returning applicants, not new applicants. *The amount of money required to fix these problems is not large. The committee believes that, in some cases, adding to the selection criteria for small science projects a consideration of their contributions to the training of students and junior-level professionals would improve NASA's ability to recruit, train, and retain a skilled workforce.*

The GSRP has allowed NASA to develop close ties with universities in the sciences. However, similar opportunities in engineering are far more limited. In addition, NASA has had a strong relationship with university faculty and their students as members of space science teams in technology development, mission planning, small-mission development, and mission operations. But there have been fewer close interactions in engineering and human spaceflight. In the committee's view, NASA could benefit significantly by expanding to the engineering disciplines its approaches to establishing relationships in the sciences at the university level.

NASA already spends a significant amount of money—over $162 million in fiscal year 2006—on education. But much of this funding is congressionally earmarked for kindergarten through grade 12 and public education programs (such as science centers and museums) that do not directly assist the agency in developing the specific workforce that NASA requires.

The committee believes that training students to design and build satellites and satellite instruments, gain hands-on experience with the unique demands of satellite and spacecraft systems environments and operations, and acquire early knowledge of systems engineering techniques is an extremely important investment for NASA to make. NASA needs to play a role in training the potential workforce in the skills that are unique to the work the agency conducts (see Figures ES.1 and ES.2). If NASA does not nurture and train its own potential workforce, there is no guarantee that any other government agency or private entity will do so, nor that the agency will receive the high-quality personnel that it requires to achieve the ambitious goals of returning humans to the Moon and eventually sending them to Mars.

The committee emphasizes further that when evaluating its future workforce requirements, NASA has to consider not only programs for students, but also training opportunities for its current employees. NASA's training programs at the agency's various field centers, which are focused on NASA's civil service talent, require support to

[5]For example, a NASA GSRP slot is valued at $30,000 and awarded for 1 year; the reward is renewable for up to 3 years. For comparison, graduate fellowship funding can reach $35,000 at NIH, $37,000 at EPA, $40,500 at NSF, $42,200 to $52,200 at DOE, and $55,000 at DOD. (Figures are from 2005. More recent data were not available as of this writing.)

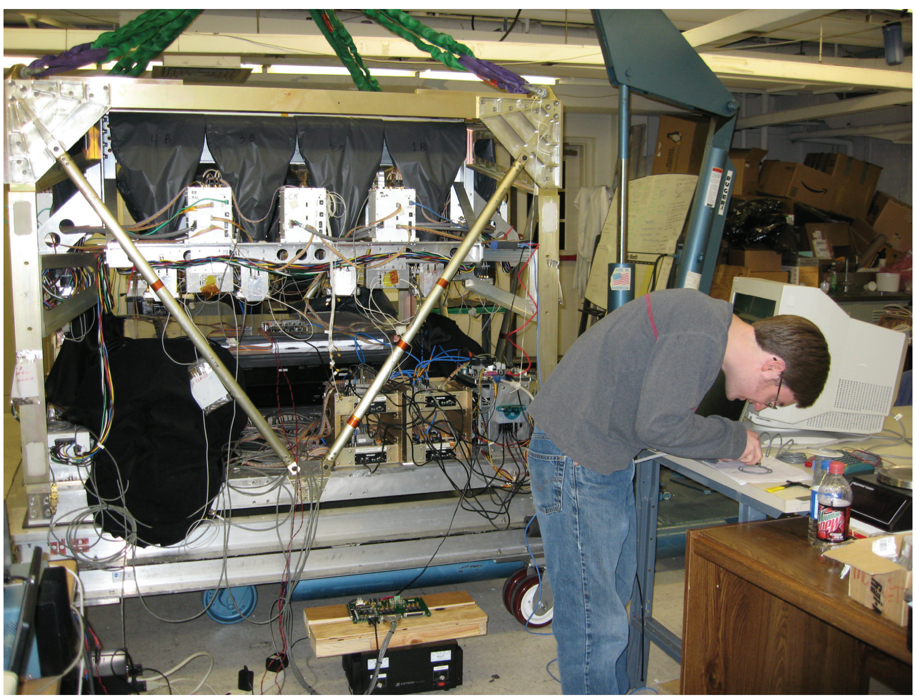

FIGURE ES.1 NASA technicians and university students require hands-on experience both to develop the skills and knowledge required for work on sophisticated space programs and to ensure that the agency has the systems engineers and program managers that it requires. (Top) A technician prepares a sounding rocket payload. (Bottom) A student works on an instrument in preparation for the Cosmic Ray Energetics and Mass (CREAM) 3 payload (http://cosmicray.umd.edu/cream) planned for launch in late 2007. SOURCE: Courtesy of NASA and the University of Maryland.

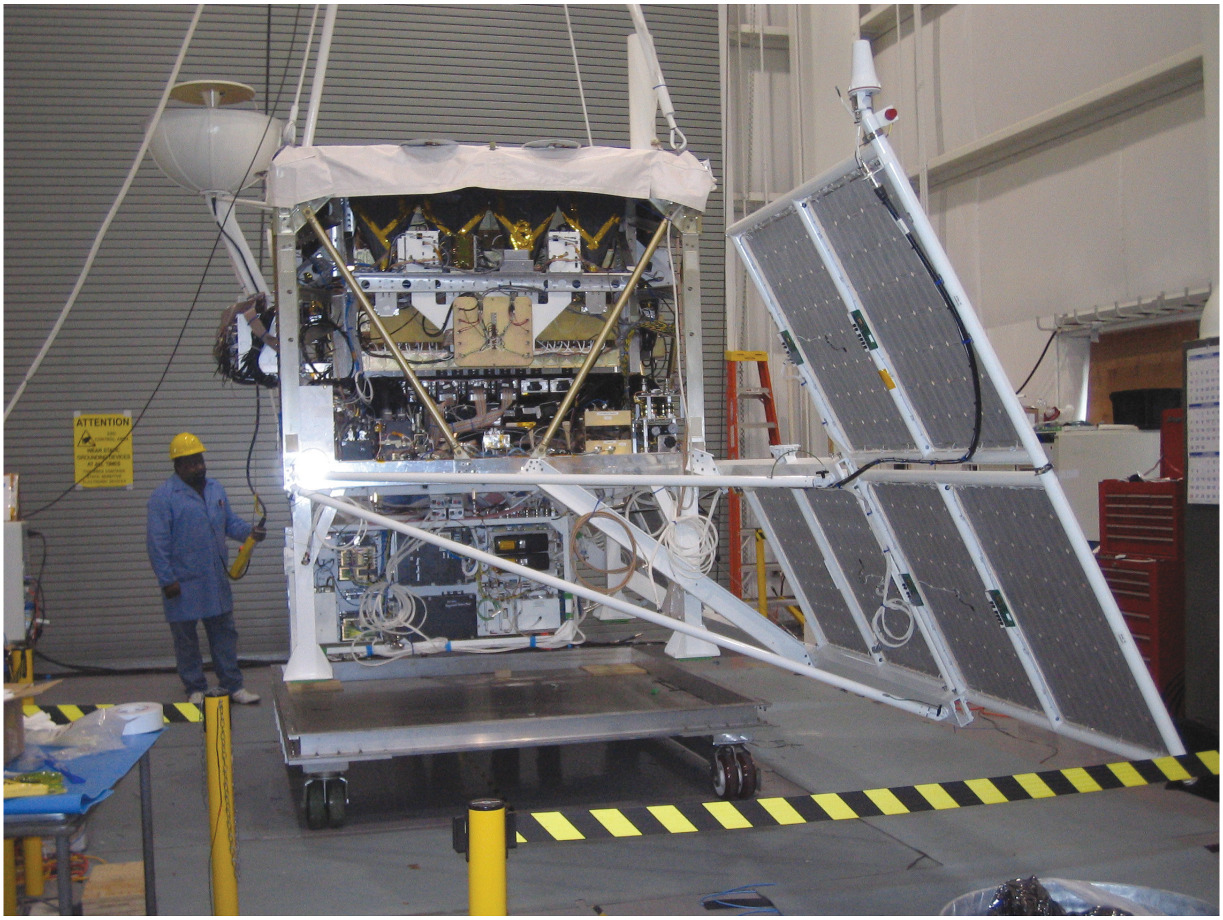

FIGURE ES.2 Some current balloon-borne payloads are in effect "mini-satellites" equipped with sophisticated subsystems and instruments. Here a NASA-sponsored Cosmic Ray Energetics and Mass (CREAM) payload is integrated at NASA Wallops Flight Facility prior to shipment to Antarctica for launch. SOURCE: See http://cosmicray.umd.edu/cream. Illustration courtesy of NASA and the University of Maryland.

prevent the agency's internal skill base from withering. Furthermore, NASA faces the risk that, if it fails to nurture its own internal workforce, skilled personnel will be attracted to other government agencies and industry.

Finally, the committee notes that not only is the contemporary workforce more fluid than it once was, but there are also new opportunities and organizations that might play a valuable role in attracting, training, and developing the workforce. These include the emerging entrepreneurial space sector, often called the "alt-space" or "new space" sector. Although to date NASA has looked at these organizations in terms of acquisition of capabilities and services (such as the Commercial Orbital Transportation Services contracts), they also offer an opportunity for tapping and developing new workforce resources.

The committee reached its conclusions after benefiting from input from public meetings at which it heard from representatives from NASA, the Department of Defense, the National Science Foundation, the Bureau of Labor Statistics, the aerospace industry, and university science and engineering schools and from analysis of documents from NASA and other organizations. The committee concluded that NASA has done much commendable work on understanding the problems it faces in the workforce arena but still has much left to do, both in understanding its requirements and in ensuring its support for programs that can fulfill them. After reviewing NASA's own workforce analyses and plans and reviewing available data, the committee developed the following specific findings and recommendations.

Finding 1: NASA has undertaken a commendable top-down (i.e., headquarters-directed) analysis of current agency needs and the skill levels of its current workforce that the committee believes is an excellent first step. But although NASA has considered workforce needs for the agency as a whole, it has not yet projected its requirements for future hiring in terms of (1) the numbers and specific skill sets of workers expected to be needed by each NASA center over time and (2) the timeframes for hiring based on anticipated retirements of the present workforce. The committee believes that understanding future hiring requirements will depend on an accurate, detailed assessment of the skills, VSE-related development capabilities, and expected attrition of the workforce for each center.

Recommendation 1: Collect detailed data on NASA workforce requirements.

The committee recommends that NASA collect detailed data on and develop accurate assessments of the capabilities possessed by the current workforce and required for the future S&T workforce.

- **Because each NASA center has unique mission requirements and the mobility of personnel between centers is limited, NASA should complete a center-developed, bottom-up assessment of the current skills, experience levels, and projected attrition of the workforce for each individual NASA center.**
- **NASA should use the data obtained from such assessments to develop a model for projecting future NASA priorities for VSE skill development and hiring by competencies, experience levels, and centers, as well as a model for the best mix of skill development conducted within NASA versus within industry.**
- **NASA should translate identified workforce needs from competencies and experience levels into specific positions to be implemented at individual centers at specific points in time.**
- **NASA should assess whether the skill levels of in-house scientists at each field center are appropriate to fulfilling that center's scientific leadership and service responsibilities and should ensure that appropriate efforts are made to maintain the scientific competency and currency of each center's scientific workforce.**
- **NASA should ensure that hiring constraints—such as pay levels, personnel ceilings, and ability to recruit suitable candidates—guide make-or-buy decisions about how staffing needs will be met.**
- **NASA should ensure that appropriate workforce strategies—including providing training for staff (e.g., through the NASA Academy of Program/Project and Engineering Leadership program), contracting out work to industry and academia, facilitating exchange programs, and hiring temporary contract and term employees—are applied at each center.**

The committee believes that it is premature to recommend a particular mix of strategies for obtaining the desired worker skill mix until NASA fully defines its staffing needs.

Finding 2: In the short term, NASA has too few program/project managers and systems engineers with the requisite experience in human spaceflight systems development to successfully oversee VSE projects. Given the lack of detailed data on NASA's near-term workforce skills and needs as well as uncertainties over NASA's budget, the committee did not attempt to assess the likely success of NASA's planned steps to address near-term workforce problems.

Recommendation 2: Hire and retain younger workers within NASA.

The committee recommends that NASA implement a long-term strategy for hiring a steady supply of younger workers and subsequently retaining those workers as they rise to senior management positions so that a balanced distribution of age and skill is maintained throughout the agency's entire workforce.

- **NASA should take full advantage of the NASA Flexibility Act of 2004, which was passed to facilitate the agency's recruitment of employees from industry. NASA has already utilized the act to a considerable extent, and the committee encourages the agency to continue to do so, as well as to inform Congress of any additional hiring flexibility that is required.**

- **NASA, working with Congress and the executive branch, should develop solutions to legal problems that limit the flow of senior and highly skilled employees from industry to NASA even when such employees are willing to accept lower salaries. Issues regarding shareholding, pensions, and perceived or actual conflicts of interest severely hamper personnel exchanges between industry and NASA. These problems stem from policy issues that cannot be resolved by NASA alone but instead require action by Congress and the executive branch working in concert with NASA.**

Finding 3: NASA's workforce requirements and challenges cannot be considered in isolation from those of other government and industry organizations. NASA is part of an aerospace workforce ecosystem in which the health and needs of one organization or sector can affect another. Thus, NASA's workforce issues require the intervention and assistance of higher-level government organizations such as the Office of Science and Technology Policy in the Executive Office of the President.

Recommendation 3: Ensure a coordinated national strategy for aerospace workforce development among relevant institutions.

The committee recommends that representatives from relevant government agencies, the aerospace industry, including the emerging private sector, and the academic community work together to develop a coordinated national strategy to ensure an effective aerospace workforce ecosystem.

Finding 4: There is a longstanding, widely recognized requirement for more highly skilled program/project managers and systems engineers who have acquired substantial experience in space systems development. Although the need exists across all of NASA and the aerospace industry, it seems particularly acute for human spaceflight systems because of the long periods between initiation of new programs (i.e., the Space Shuttle program in the 1970s and the Constellation program 30 years later). NASA training programs are addressing some of the agency's requirements in this experience base, but the current requirement for a strong base of highly skilled program/project management and systems engineering personnel, and limited opportunities for junior specialists to gain hands-on space project experience, remain impediments to NASA's ability to successfully carry out VSE programs and projects.

Recommendation 4: Provide hands-on training opportunities for NASA workers.

The committee recommends that NASA place a high priority on recruiting, training, and retaining skilled program/project managers and systems engineers and that it provide the hands-on training and development opportunities for younger and junior personnel required to establish and maintain the necessary capabilities in these disciplines. Specific and immediate actions to be taken by NASA and other parts of the federal government include the following:

- **In establishing its strategy for meeting VSE systems engineering needs, NASA should determine the right balance between in-house and out-of-house work and contractor roles and responsibilities, including the use of support service contractors.**
- **NASA should continue and also expand its current employee training programs such as those being conducted by the Academy of Program/Project and Engineering Leadership (APPEL). To facilitate the development of key systems engineering and project management skills, NASA should increase the number of opportunities for entry-level employees to be involved in hands-on flight and end-to-end development programs. A variety of programs—including those involving balloons, sounding rockets, aircraft-based research, small satellites, and so on—can be used to give these employees critical experience relatively early in their careers and allow them to contribute as systems engineers and program managers more quickly.**

Finding 5: NASA relies on a highly trained technical workforce to achieve its goals and has long accepted a responsibility for supporting the training of those who are potential employees. In recent years, however, training for students has been less well supported by NASA. A robust and stable commitment to creating opportunities at the university level for experience in hands-on flight mission development, graduate research fellowships for science and engineering students, and research is essential for recruiting and developing the long-term supply of competent workers necessary to implement NASA's future programs.

- Faculty research not only is fundamental to student training but also leads to the development of new technology and tools for future applications in space. Programs supporting critical scientific and technological expertise are highly desirable.
- Hands-on experience for students is provided by suborbital programs, Explorer and other small spacecraft missions, and design competitions, all of which rely on continuing NASA support.
- The Graduate Student Researchers Program supports the education and training of prospective NASA employees and deserves augmented support.
- Undergraduate and graduate co-op student programs are particularly effective in giving students early hands-on experience and in exposing students and NASA to each other to help enable sound career choices and hiring decisions.

Recommendation 5: Support university programs and provide hands-on opportunities at the college level.

The committee recommends that NASA make workforce-related programs such as the Graduate Student Researchers Program and co-op programs a high priority within its education budget. NASA should also invest in the future workforce by partnering with universities to provide hands-on experiences for students and opportunities for fundamental scientific and engineering research specific to NASA's needs. These experiences should include significant numbers of opportunities to participate in all aspects of suborbital and Explorer-class flight programs and in research fellowships and co-op student assignments.

Finding 6: Although NASA's primary role is not education or outreach, improved support of the higher-education community and of young professionals is critical to maintaining a sufficiently talented workforce. Involvement in providing development and educational opportunities, especially hands-on flight and vehicle development opportunities, will pay future dividends not only by encouraging larger numbers of talented students to enter the field, but also by improving the abilities of incoming employees. Indeed, a failure to invest in today's students and young professionals will ultimately lead to a crisis when that generation is expected to assume the mantle of leadership within the U.S. aerospace community.

Recommendation 6: Support involvement in suborbital programs and nontraditional approaches to developing skills.

The committee recommends that NASA increase its investment in proven programs such as sounding rocket launches, aircraft-based research, and high-altitude balloon campaigns, which provide ample opportunities for hands-on flight development experience at a relatively low cost of failure.

Rather than viewing sounding rockets, aircraft-based research, and balloon programs simply as low-cost, competed, scientific missions, NASA should also recognize as an equal factor in the criteria for their selection their ability to provide valuable hands-on experience for its younger workers and should investigate the possibility of funding such programs through its education budget.

In addition, NASA should take advantage of nontraditional institutions and approaches both to inspire and to train potential future employees. Investment in programs such as Centennial Challenge prizes and other innovative methods has the potential to pay benefits many times greater than their cost, by simultaneously increasing NASA's public visibility, training a new generation of workers, and pushing the technology envelope.

Strategic planning for workforce issues is difficult because budget and program decisions often have major impacts on the workforce that make strategic planning irrelevant. The committee heard from industry representatives who stated that NASA's ability to attract junior-level personnel and retain senior personnel will be heavily influenced by perceptions about how compelling and stably funded the Vision for Space Exploration is. The committee thus believes that NASA must adopt policies that, while relatively inexpensive, can have a longer-term impact on its ability to obtain the highest-quality personnel.

1

Introduction

Created in an era of Cold War competition between the superpowers, NASA assumed a highly symbolic role as a demonstration of overall U.S. scientific and technological capability. It is thus not surprising that the health of the U.S. scientific and technological workforce has been an important theme throughout the history of the U.S. space program. In its early years, NASA officials took pride in their agency's "can do" style and the ability of its employees and those of the NASA's private sector partners to accept and succeed at some of the most challenging tasks ever undertaken. The excitement of space exploration in the 1960s invigorated the U.S. technological workforce, drawing young people to study and eventually pursue careers in science, engineering, and mathematics.

As NASA has matured and evolved, however, it has played a smaller role in drawing people into scientific and technical careers. Instead, an issue of increasing concern is the agency's ability to compete with other scientific and technical agencies and industries to acquire the workforce essential to achieving the nation's goals for future space exploration and exploitation. As the cadre of people entering the space community in the 1960s reaches retirement age, it is imperative to ask whether and how these experts will be succeeded by new generations of experts.

Recurring concern about this issue has been evident at NASA. For instance, in December 1999, NASA's then-administrator Daniel Goldin stated that the retirement of NASA's workforce was an "overwhelming issue" that would overshadow the agency's future for the next 5 to 10 years.[1] More recently, NASA's current administrator Michael Griffin stated that "twenty-five percent of NASA's workforce reaches retirement age in the next five years and it will not be different in our contractor community."[2]

Outside NASA, other organizations have referred to a "crisis" in the aerospace industry.[3] The Government Accountability Office reported in early 2003 that

> NASA is facing shortages in its workforce, which could likely worsen as the workforce continues to age and the pipeline of talent shrinks. This dilemma is more pronounced among areas crucial to NASA's ability to perform its mission, such as engineering, science, and information technology.[4]

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[1]See www.space.com/news/nasa_workforce_991215.html.

[2]See www.nasa.gov/pdf/133896main_ESAS_rollout_press.pdf, p. 35.

[3]Commission on the Future of the United States Aerospace Industry, *Final Report of the Commission on the Future of the United States Aerospace Industry*, 2002. Available from the U.S. Department of Commerce, Washington, D.C.

[4]"Performance and Accountability Series: National Aeronautics and Space Administration," Government Accountability Office report GOA-03-114, January 2003; http://www.gao.gov/pas/2003/d03114high.pdf.

Congress responded to these concerns by approving the NASA Flexibility Act of 2004.[5] Among the act's provisions was the expansion of NASA's authority to offer employee recruitment and retention bonuses. The committee believes that this act has given NASA a valuable tool in recruiting and hiring workers with the necessary skills. It applauds the agency's initial efforts in taking advantage of the act's provisions and encourages NASA to utilize the act fully. However, the committee concluded that further congressional and executive branch involvement may be necessary, particularly to address the legal and ethical issues that accompany recruiting skilled personnel from industry.

The committee believes that the general focus on the age of the NASA workforce and a looming "retirement crisis" tends to obscure more complex and subtle demographic issues. Although a massive and simultaneous wave of retirements among eligible employees would be a devastating blow to the agency, it is likely that NASA will continue to retain employees beyond retirement age and to engage the retiree community as consultants and mentors, as it has done in the past. The committee believes that the most relevant issue facing NASA's workforce is not its age, but rather the number and distribution of skilled employees within the agency and the ability of the agency to ensure that it has, and will continue to have, an adequate supply of trained employees.

The committee notes comments made before a House Space and Aeronautics Subcommittee hearing in 2002 by NASA's then-administrator Sean O'Keefe, who stated that although there were fewer hires in fiscal year 2001 than in the previous year, NASA needed almost twice as many recruitment bonuses to attract the desired recruits. "Even utilizing all the tools at hand, we are at a disadvantage when competing with the private sector," he said.[6]

The workforce situation at NASA is highly fluid and complex. The agency is currently hiring very few new employees and has recently emerged from having excess employees—the so-called uncovered capacity problem. NASA does need to attract, train, and retain highly skilled personnel, but the committee believes that it is difficult to characterize the agency's needs in aggregate numbers and that only a detailed examination of workforce needs can indicate where the problems lie.

The context for NASA's future workforce was sharpened in January 2004 when President George W. Bush announced the new national Vision for Space Exploration (VSE) with the fundamental goal "to advance U.S. scientific, security, and economic interests through a robust space exploration program" that would involve human and robotic exploration of space, including sending humans back to the Moon and later to Mars.[7] Implementation of this policy has added new clarity to the direction and potential scope of the nation's human spaceflight program, and consequently has provided the basis for a more precise assessment of future space program workforce needs. In September 2005, NASA Administrator Michael Griffin unveiled the agency's plan for the human lunar exploration program, making clear that one of his goals was to avoid losing engineering experience and personnel during the transition from the Shuttle and Space Station era to the lunar exploration era.

Congress was also concerned about NASA's workforce and in the NASA Authorization Act of 2005 directed NASA to develop "a human capital strategy to ensure that NASA has a workforce of the appropriate size and with the appropriate skills to carry out the programs of NASA."[8] The National Space Policy released by the White House in early October 2006 also emphasized the importance of a skilled workforce. The policy stated:

> Sustained excellence in space-related science, engineering, acquisition, and operational disciplines is vital to the future of U.S. space capabilities. Departments and agencies that conduct space related activities shall establish standards and implement activities to develop and maintain highly skilled, experienced, and motivated space professionals within their workforce.[9]

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[5] S. 610, "The NASA Flexibility Act of 2004," Public Law No. 108-201.

[6] Testimony by Sean O'Keefe before House Science Committee Hearing on NASA's Work Force, July 18, 2002.

[7] National Aeronautics and Space Administration (NASA), *The Vision for Space Exploration*, NP-2004-01-334-HQ, NASA, Washington, D.C., 2004.

[8] House Report 109-173, NASA Authorization Act of 2005.

[9] See U.S. National Space Policy, 2006, which can be found at the Office of Science and Technology Policy Web site, http://www.ostp.gov/html/US%20National%20Space%20Policy.pdf.

WORKFORCE ISSUES FOR THE FEDERAL GOVERNMENT

The modern U.S. scientific and technical enterprise forged during World War II is based on a triangular cooperative working relationship among government institutions, industry, and academia. NASA has relied on this relationship since its creation in 1958. For example, university researchers under NASA sponsorship perform most of the scientific analysis of the data returned from NASA missions, and most of the spacecraft are built by industry. Very few of these activities are actually conducted by NASA employees, whose primary focus is managing and overseeing these projects and preparing the agency's budget.

Each element of the triad has different roles and challenges associated with its workforce. Academia has a primary role in educating and supplying the workforce for NASA and industry, and hence has an interest in policy solutions that endorse educational funding increases. The academic sector not only plays a major role in supplying the scientists and support staff to conceive, develop, and conduct the research studies in NASA's science programs, but also conducts the advanced development of scientific instrument technologies for future science missions as well as both generating and reporting on the majority of the scientific results obtained from current and past missions. Industry has been the major developer of space mission systems, and it shares responsibility with NASA for the operation of those systems. NASA has traditionally played a key role in the design and development of new technologies for human exploration and for space mission operations. NASA, industry, and universities all have played critical roles in providing on-the-job training for space program professionals.

There is no shortage of relevant literature on the problems facing the federal government concerning the scientific and engineering workforce. Several studies have focused on a specific sector or government agency. For example, a 2001 Booz Allen Hamilton study for the National Reconnaissance Office on the military space industrial base echoed the statements of NASA administrators, warning that the average age of the space workforce was increasing.[10] More recently, the military services have experienced serious problems in the acquisition of several DOD space systems, problems blamed partly on funding instability and overly ambitious requirements, but also on management inadequacies caused by poorly trained or unqualified personnel. Recent discussion in the DOD has raised the charge that the United States is currently suffering from a shortage of experienced and competently trained technical management personnel in a large number of areas, not simply in space programs. Other studies have focused even more narrowly on specific aspects of government acquisition. The committee notes that examples of technical workforce shortages exist outside the United States as well. For instance, a RAND Corporation study of the United Kingdom's shipbuilding and submarine manufacturing base identified the dangers in allowing specific areas of expertise and workers' skill sets to atrophy and disappear, noting that reconstituting lost capabilities later may be very expensive, and recommending that procurement be staggered so as to preserve this expertise.[11]

As several surveys of the overall science and engineering workforce have demonstrated, fields such as aerospace engineering that once were highly attractive to technically trained college students have now been supplanted by other fields, such as bioengineering. One could argue that congressional action in recent years to double the National Institutes of Health budget has helped fuel the migration to biomedical and biotechnology fields in much the same way that the infusion of funding into NASA during the Apollo era fueled the moves to aerospace fields in the 1960s. One of NASA's challenges will be to maintain and nurture its workforce at a time when there are attractive alternatives in other fields, when other employers such as the DOD are competing to draw from the same pool of potential employees, and when a large infusion of new funding into the space program is not widely anticipated.

NASA can learn from studies conducted of other government agencies, and even non-U.S. agencies such as the United Kingdom's Royal Navy. But perhaps the most important lesson for NASA is that it is competing with other government agencies and private industries that are themselves concerned about attracting and retaining highly skilled personnel. NASA officials cannot expect that the uniqueness and presumed excitement of its mission will

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[10]Gen. Thomas S. Moorman, Jr., U.S. Air Force (retired), testimony before the House Subcommittee on Space and Aeronautics, May 15, 2001.

[11]John F. Schank, Jessie Riposo, John Birkler and James Chiesa, *Sustaining Design and Production Resources: The United Kingdom's Nuclear Submarine Industrial Base*, Vol. 1, The RAND Corporation, 2005.

FIGURE 1.1 The P3/P4 truss segment of the International Space Station (ISS) being prepared for launch in summer 2006. Although it was a massive development program, system engineering and integration for the ISS were done primarily by a prime contractor, not NASA personnel. SOURCE: Courtesy of Troy Crider, NASA.

be sufficient to ensure that it will acquire the quality workforce that it needs. NASA will have to develop specific solutions tailored to its own requirements.

THE SCOPE OF NASA'S NEW ACTIVITIES

President Bush's civil space exploration policy, announced in January 2004, calls for human lunar missions as early as 2015 but no later than 2020. Although neither the president nor NASA explicitly endorsed a specific timeline for a human Mars landing, the new policy does embrace human missions to Mars as an eventual goal after the return to the Moon, and NASA's leadership has stated that a human Mars mission could occur sometime in the 2020s. As a consequence of this redirected U.S. space policy, NASA has been restructured to include four major program offices: the Exploration Systems Mission Directorate and the Science Mission Directorate, with overlapping responsibilities for implementing the VSE; the Space Operations Mission Directorate, which is responsible for the Space Shuttle program and for assembly and operation of the International Space Station; and the Aeronautics Research Mission Directorate.

In fall 2005, NASA formally unveiled the results of its Exploration Systems Architecture Study (ESAS), which outlined the overall engineering approach to achieving the lunar landing goal; the final version of the ESAS report was released in January 2006.[12] The space exploration approach outlined requires a new Orion spacecraft (formerly the Crew Exploration Vehicle) for ferrying humans into space, a lunar surface access module for landing astronauts on the Moon, and two new rocket vehicles for carrying these spacecraft into space. The rocket vehicles

[12]National Aeronautics and Space Administration, *Exploration Systems Architecture Study Final Report*, NASA, Washington, D.C., 2005.

FIGURE 1.2 Technicians replacing space shuttle tiles. NASA will face a significant challenge in transitioning its workforce from shuttle operations to development of new space vehicles and then eventually back to operations. SOURCE: Courtesy of NASA.

will be the Ares I (formerly the Crew Launch Vehicle) and the Ares V heavy-lift launch vehicle. Both will rely on Space Shuttle components as well as rocket engines from other launch vehicles. Although the specifics of the lunar landing architecture are subject to change, development of these new spacecraft and launch vehicles clearly presents a technical challenge that will require significant systems integration expertise.

NASA last undertook parallel development of multiple launch vehicles and spacecraft during the 1960s and of a new human spacecraft requiring substantial in-house expertise when it developed the Space Shuttle in the 1970s. The International Space Station utilized a prime contractor as the systems engineering and integration lead and provided a limited number of development systems engineering and program management learning opportunities for the NASA workforce (Figure 1.1). Now the agency is undertaking development of the Orion and Ares I, and in a few years it will begin development of the Ares V and the lunar landing vehicle. As it begins work on the lunar outpost announced in December 2006, NASA will have to undertake further developments such as habitation modules on the Moon and unpressurized and pressurized lunar rovers. Clearly these new projects will require that NASA have significant in-house expertise to manage them (Figure 1.2).

The ESAS report did not provide a rationale for or an outline of lunar science goals, but clearly lunar science will also receive significant new attention by the agency.[13] NASA is pursuing the development of two precursor

[13]Lunar science is currently the subject of an ongoing NRC study (see *The Scientific Context for Exploration of the Moon: Interim Report*, The National Academies Press, Washington, D.C., 2006) and was also addressed by a spring 2007 workshop sponsored by the NASA Advisory Council. In addition, in December 2006 NASA released the preliminary results of its lunar architecture study and has begun work on a lunar science architecture study as well.

robotic lunar spacecraft and continuing its robotic exploration of Mars. Expert personnel will also be needed to manage these efforts and interpret the data collected.

Other major aspects of NASA's overall space program that are not exclusively part of the VSE may affect achievement of the VSE in various ways. These include the agency's space science program, encompassing planetary science, Earth sciences, heliophysics, and astrophysics. The NASA administrator, and the Bush administration's new national space policy, have indicated that NASA is committed to a balanced program of exploration that includes research to understand Earth, the solar system, and the larger universe that extends well beyond the solar system, in addition to the human space program. In the past NASA has also supported a broadly based research program in the physical and biological sciences, microgravity science, and aeronautics, but recently the microgravity programs have been scaled back and focused more narrowly on (primarily biomedical) areas that NASA views as directly supporting nearer-term aspects of the VSE.[14] Aeronautics has also experienced significant budget reductions.

In statements from numerous experts outside NASA during its January 2006 workshop, briefings during its meetings in 2006, and in the report of NASA's Systems Engineering and Institutional Transition Team (SEITT), the committee heard that, in the short term, the agency lacks the required in-house talent to successfully oversee VSE projects. In particular, it lacks several hundred skilled personnel in the area of program/project management and systems engineering.[15] The committee believes that NASA recognizes this shortfall and has taken some steps to correct it, such as implementation of the "smart buyer" program to recruit retired employees with Space Shuttle development experience. The committee regards as limited its own ability to provide recommendations to solve the short-term problem of NASA's current lack of required in-house expertise.

APPROACH TAKEN IN THIS STUDY

The committee defines the workforce needed to accomplish the Vision for Space Exploration in its broadest sense. That is, to succeed in accomplishing the VSE's goals, the nation will need the best expertise and best efforts of workers *not only inside NASA but also in NASA's partner institutions in industry, academia, and other federal agencies.* This national civil space workforce is highly geographically dispersed, as are NASA's own field centers. Given the involvement of industry and universities, science and technology workers who will contribute to the VSE effort will be found in every state in the Union.

NASA states that it will conduct a balanced program that seeks to support many different efforts, but the agency is highly constrained by the budget that Congress grants it, as well as by expectations placed on NASA by the new space exploration policy. The committee therefore examined the issue of science staffing as well as engineering staffing and, at the request of Scott Pace, the NASA associate administrator for program assessment and evaluation, also discussed activities currently conducted by NASA that could perhaps be phased out. The committee assumed that NASA's budget will remain relatively flat over the life of the VSE and that the VSE will be pursued over the period that NASA intends.

NASA currently has a budget-driven goal of reducing the agency's total workforce by 2,000 employees between 2006 and 2011. Although the committee appreciates NASA's need to operate within a constrained budget, it is concerned that such substantial reductions could result in the agency losing needed trained personnel. Without a carefully planned strategy for determining the agency's personnel needs and how it will achieve them, NASA could inflict damage on itself during this reduction. The chapters that follow examine the basis for these concerns in more detail.

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[14]The NASA Authorization Act of 2005 calls for a balanced scientific program that includes all of the research disciplines cited here, but a 2006 NRC report, *Assessment of Balance in NASA's Science Programs* (The National Academies Press, Washington, D.C.), calls into question whether NASA's current plans can sustain an overall program that is balanced and healthy.

[15]NASA, Office of Program Analysis and Evaluation, *Systems Engineering and Institutional Transitions Study, Final Report*, April 5, 2006.

2

Overall Assessment of Workforce Supply and Demand

The committee was asked to evaluate the current and projected demographics for the aerospace engineering and space science workforce and how any potential shortages might affect NASA. The committee found a substantial amount of data on the production of new engineers and space scientists. But the committee also determined that the data are insufficient to assess NASA's requirements for employees who are not only educated but also highly skilled. What the data often fail to indicate is the degree of skill present in the potential workforce.

NASA'S CURRENT WORKFORCE DEMOGRAPHICS

As of January 2007, NASA employed more than 18,000 workers distributed among 10 field centers throughout the country and its Washington, D.C., headquarters. One of the common yardsticks for measuring NASA's current workforce is its age distribution. NASA administrators as well as members of Congress have noted that a relatively large percentage of the agency's workforce will soon be eligible for retirement, many in no more than 5 years, and in any case considerably less time than the time required to complete major new projects. A "retirement wave" and consequent loss of people with important experience in NASA missions and research would clearly be detrimental to NASA's efforts. Although the potential for a mass exodus may be exaggerated, there is clear evidence that NASA's employee age distribution has changed as a result of policies enacted during the 1990s.

NASA officials reported to the committee that the current age distribution of the agency's civil service workforce peaks in the age range from 40 to 44 (Figure 2.1).[1] By comparison, the age distributions for the aerospace workforce generally and the federal government both peak at greater ages than that for NASA, the peak for the federal workforce being nearly a decade beyond the peak for NASA. The age distribution for the aerospace workforce is currently double peaked, with both peaks at or above the peak for NASA. The age distribution for the total U.S. workforce peaks in the same age range as that for NASA but is much broader, indicating that the U.S. workforce has a far greater number of young workers than does NASA.[2]

The data in Figure 2.1 indicate that NASA's workforce is significantly younger than that of the aerospace

[1]Although NASA refers to the age distribution of its workforce, it is illegal under the Age Discrimination and Employment Act to use age as a criterion for hiring or layoffs if it results in an adverse impact on workers over 40. The committee assumes that age is generally being used as a proxy for experience. In addition, the age distribution is useful for predicting openings likely to arise because of retirements.

[2]Data provided to the committee by two of NASA's contractors, United Space Alliance and Swales, and by the Space Division of Johns Hopkins University's Applied Physics Laboratory, showed age distributions for their workforces that were similar to the distributions for NASA.

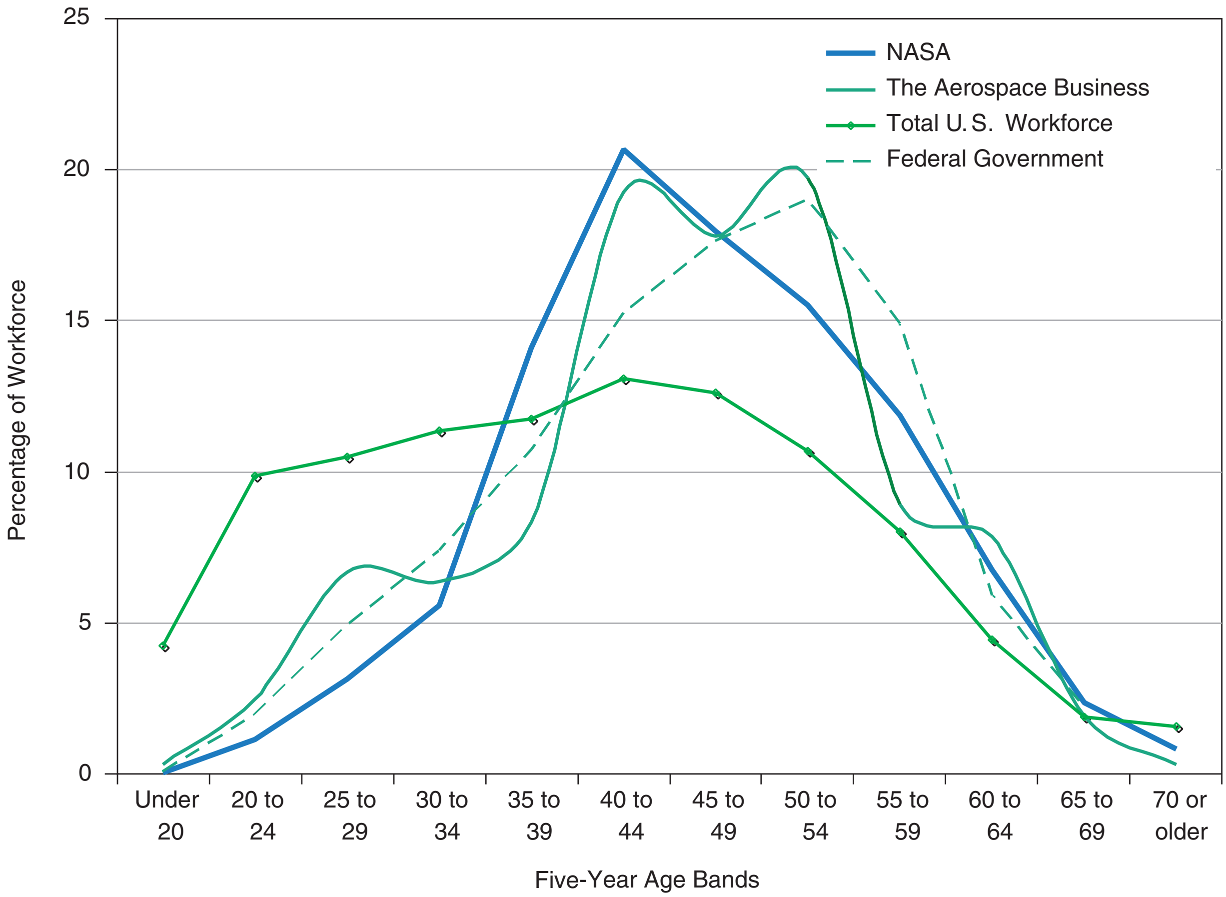

FIGURE 2.1 The age distribution of NASA's current workforce compared to the age distributions for the aerospace sector, the federal government, and the total U.S. workforce. NOTE: The line for aerospace business is based on very imprecise data. SOURCE: Garth Henning and Richard Leshner, NASA, presentation to the Committee on Meeting the Workforce Needs for the National Vision for Space Exploration, February 22, 2005. Courtesy of NASA.

workforce generally, the more relevant comparison population. The fraction of the NASA workforce in the age range from 35 to 55, the span generally agreed to represent the more productive years of technical staff, is 68 percent, nearly identical to that for the aerospace industry generally over the same age range. However, more than one-third of NASA's workforce is in the age range from 35 to 45, compared to only 27 percent of the aerospace workforce generally. In addition, the aerospace industry workforce's second peak, in the age range from 50 to 55, a peak that is lacking in NASA's workforce, represents people with vital experience who are present in higher numbers in industry than at NASA. It appears that NASA's workforce issue is not one of age or sheer numbers; it is one of skill and experience. Most of the space hardware development over the past one to two decades has been done by industry, not NASA, and therefore agency employees have not benefited from this experience.

Almost 60 percent of NASA's civil service employees are scientists and engineers. Within that cadre, about 85 percent are engineers and nearly 10 percent are scientists. According to NASA officials who briefed the committee, the average age of NASA scientists and engineers is 45.8; 24 percent are younger than 40, 67 percent are between 40 and 59, and 9 percent are 60 or older. NASA has determined that 12 percent of its engineers and 21 percent of its scientists are now eligible to retire, and it projects that in 2011, 28 percent of its engineers and 45 percent of its scientists will be eligible to retire.

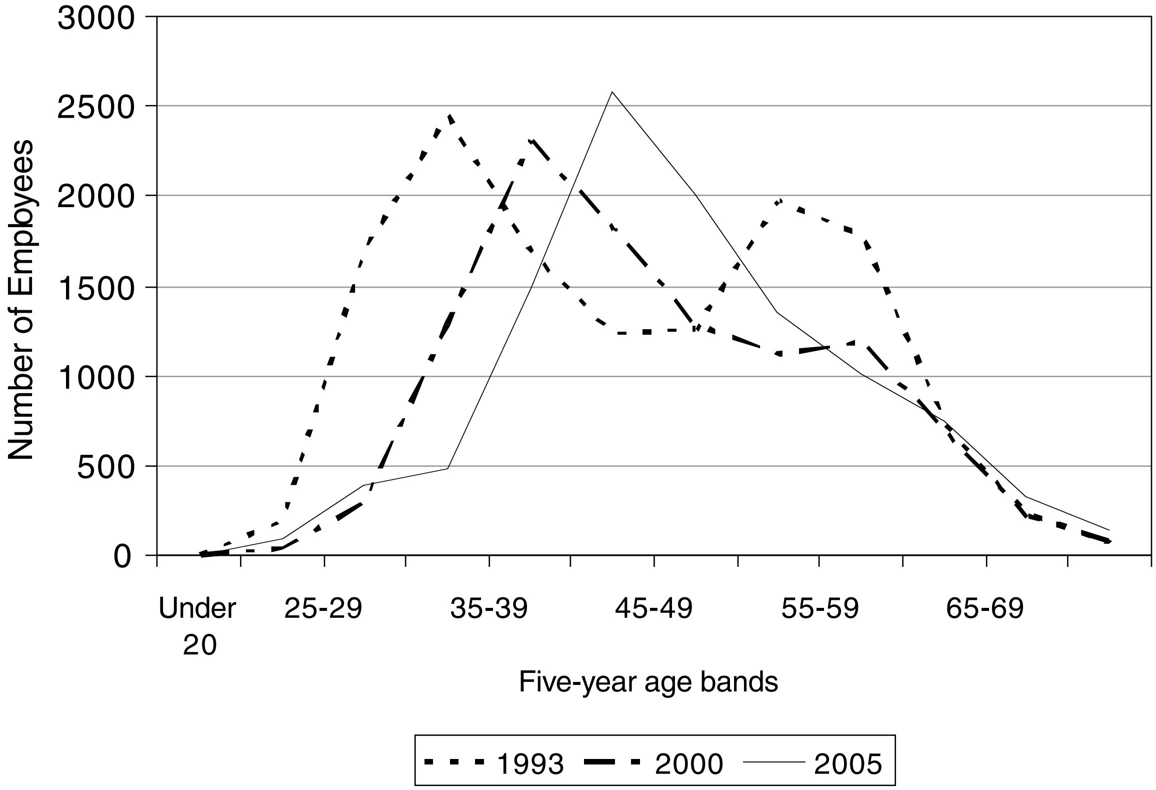

FIGURE 2.2 Average age of NASA employees at three separate periods. SOURCE: Courtesy of NASA.

The committee believes that sudden mass retirement is an unlikely future scenario. Offsetting the prospects for a retirement wave in the near future is the fact that NASA is now experiencing an overall annual attrition rate of only 3.5 percent and a slightly lower rate for scientists and engineers.[3] These rates are substantially lower than retirement rates for the federal government, which are around 7 percent.

However, the committee does note a slightly alarming trend: NASA's workforce has been steadily aging since the early 1990s (Figure 2.2).

In response to the committee's interim report,[4] NASA's Office of Human Capital Management explained demographic trends at the agency over the past decade and a half. Starting in 1989 and continuing into the early 1990s, NASA instituted a program to attract younger workers to the agency, hiring substantial numbers of college "fresh outs." By the mid-1990s the agency had adopted policies for downsizing, and hiring restrictions meant that for nearly a decade, very few younger employees (such as recent university graduates) were hired by NASA. By 2000 NASA downsizing had ended and the agency realized it had opened up competency gaps in parts of the workforce. *Efforts to close these gaps did lead to increased hiring of younger workers, but they remained only a relatively small portion of the total NASA science and engineering workforce. In 2003 NASA instituted a corporate*

[3]U.S. Census Bureau and Bureau of Labor Statistics data show the total federal government attrition rate to be about 7 percent per year and the attrition rate for the total U.S workforce to be running recently at above 40 percent per year.

[4]National Research Council, *Issues Affecting the Future of the U.S. Space Science and Engineering Workforce: Interim Report*, The National Academies Press, Washington, D.C., 2006. NASA responded to this interim report in a meeting, and written materials and comments presented to the committee were incorporated into this final report.

recruitment effort "to again focus on bringing in young talent as the agency recognized the importance of balancing the demographic." However, this effort was halted due to budget cuts.[5]

Thus, as Figure 2.2 indicates, the overall age distribution of NASA's workforce has increased steadily over the years, and the percentage of younger employees has decreased. If this steady march toward an older workforce continues, the agency will not have enough people moving up through the ranks to accomplish important tasks in the next decade, when the VSE is implemented.

The committee believes that the key to maintaining a reasonable distribution of age versus skill is for NASA to have in place a long-term hiring strategy that provides a sufficient supply of younger workers to maintain a profile similar to that shown for NASA in Figure 2.1, but halting the steady increase in average age as seen in Figure 2.2. NASA has stated that the agency is not currently taking such an approach. The committee urges that NASA implement a long-term hiring strategy for providing a steady supply of young workers to maintain a balanced distribution of age versus skill.

The committee believes that NASA wages are competitive with those industry offers at the lower to middle grades. For example, from 2001 to 2005 engineering salaries at NASA rose from a mean of $80,195 to $97,998. According to the Bureau of Labor Statistics, for the same period the mean salary for aerospace engineers in the United States increased from $71,380 to $85,450. Not only were NASA wages higher than the national average for the period, but they also increased at a faster rate—22.2 percent for NASA engineers compared to 19.7 percent for aerospace engineers in the United States.

Currently NASA is reducing the size of its workforce slightly and eliminating engineering positions. It offers competitive wages with industry for engineering positions. The committee concluded that there is no short-term evidence of a looming workforce problem and that salaries are not an issue at the lower ends. However, NASA has trouble attracting the more highly skilled talent that it requires. Although the committee lacked statistical or survey data on this subject, anecdotal evidence it collected indicated that mid-level engineers at NASA were unwilling to wait for more senior positions to open at the agency (something that could take a long time due to the agency's general low attrition rate) and were willing to leave for more lucrative positions in industry. In addition, anecdotal information collected by the Aerospace Industries Association indicates that salaries for senior-level engineers in industry can reach $140,000 to $185,000 a year, far in excess of what is available at NASA.[6]

LABOR MARKET PROJECTIONS

Viewed in the context of the larger labor market, NASA's difficulty with finding employees who have the requisite skills and experience extends to other agencies in the federal government as well, according to available data. The Department of Defense (DOD) currently employs 43 percent of all the scientists and engineers employed in the federal government. In 2002 DOD's workforce included 27 percent of all federal scientists (a substantial fraction of whom are computer and mathematical scientists in the DOD) and 67 percent of all federal engineers, including nearly 80 percent or more of all federal electrical, industrial, and mechanical engineers. Aerospace engineers in the DOD accounted for 43 percent of the federal total aerospace engineers in 2002.

In the early 2000s Booz Allen Hamilton conducted two studies for the Office of the Secretary of Defense and the National Reconnaissance Office—the Space Industrial Base Study (SIBS)[7] and the Space R&D Industrial Base Study (SRDIBS).[8] The SIBS noted a bimodal age distribution in the workforce with peak numbers clustering around 30 to 35 years and 45 to 50 years. Most industry CEOs who were interviewed for the SIBS identified workforce issues as being especially critical. Competition was found to be increasing for a limited number of

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[5]NASA Office of Human Capital Management, "Comments on NRC Report *Issues Affecting the Future of the U.S. Space Science and Engineering Workforce,*" NASA, Washington, D.C., May 2006.

[6]Industry also provides added attractions that could include signing bonuses (ranging from $15,000 to $30,000 according to one source), faster promotion, stock options, retirement benefits, reimbursement of relocation expenses, and a wider range of interesting programs. Industry also offers options to foreign engineers who might face restrictions within government. This suggests that although NASA can provide competitive wages at the lower to middle grades, a lack of additional benefits may be a recruiting disadvantage.

[7]Booz Allen Hamilton, *Space Industrial Base Study*, Washington, D.C., December 2000.

[8]Booz Allen Hamilton, *Space R&D Industrial Base Study*, Washington, D.C., August 2002.

available scientists and engineers. The subsequent SRDIBS reported some easing in the competition for scientists and engineers that had been created earlier by the Internet dot-com expansion, but the need to attract, retain, and train new workers in critical skills was seen as a continuing or growing problem. A 2004 Aerospace Workforce Review conducted by the National Defense Industrial Association (NDIA) concluded that nearly 10 percent of job vacancies were not being filled.[9] As in the SIBS and SRDIBS, certain specific skill areas, such as systems engineering, optical design engineering, and software engineering, were identified as being particularly critical and difficult to fill.[10]

The volatility of the market for national security space projects may be a particular obstacle to predicting the skills that will be in demand beyond the near term. Furthermore the DOD—like NASA—requires that most in-house scientists and engineers be U.S. citizens who are eligible to receive security clearances.

Data from the Aerospace Industries Association (AIA), which has tracked employment and business trends in the aerospace industry—including civil aviation, military systems, and space systems—for many years, show that the size of the overall aerospace workforce declined from 1990 through 1995 and remained more or less flat from 1995 through 2005. Moreover, the fraction of the total U.S. science and engineering workforce represented by aerospace fell from about 30 percent in 1965 to 2 to 3 percent in 2002. Nevertheless, AIA projections anticipate a modest level of growth in aerospace industry sales through 2011, probably in the range of 4 to 5 percent per year. The projected growth in business, combined with the potential for retirements from an aging aerospace workforce, suggest growing demand in the aerospace labor market.

The difficulty of identifying and filling gaps in workforce categories was illustrated at the committee's January 2006 workshop by Joan Burrelli from the National Science Foundation's (NSF's) Division of Science Resources Statistics, who presented NSF data showing that in 2003, of the approximately 350,000 degree holders in aerospace engineering and space science, about 270,000, or 77 percent, were *not* employed as aerospace engineers or space scientists.[11] Similarly, the NSF data indicated that of the 200,000 workers who were employed as aerospace engineers or space scientists, about 120,000 did not hold degrees in those fields (Figure 2.3). Thus in 2003, only about 80,000 workers, corresponding to 23 percent of the degree holders and 40 percent of the aerospace engineering and space science workforce, were actually working in the field of their degree. However, many may be working in related fields, such as technical management.

The committee notes that, in addition to indicating the complexities affecting labor market projections, this situation also illustrates the point that people with strong technical backgrounds can often quite readily acquire the specialized knowledge needed for work in different (but related) fields.

Burrelli also mentioned three likely influences on future natural science and engineering enrollment and graduation trends. First, the college-age population in the United States is expected to begin to decline after 2015. Second, the number of foreign students in the United States as temporary residents has been declining since September 2001, although the number of permanent residents is still growing. Third, enrollments tend to be very sensitive to employment opportunities, with first-time enrollments in a field declining in response to rising unemployment in the field, but with graduate student enrollments tending to rise for a year or two when the employment picture softens.

The Bureau of Labor Statistics (BLS) projects an 8 percent growth in total employment between 2004 and 2014 for aerospace engineers and a 7 percent growth for astronomers and physicists, compared with a projected 21 percent increase for the total of all science, technology, engineering, and mathematics occupations.[12]

In the committee's view, BLS projections are, at best, estimates of what will happen. The projections have been particularly poor at dealing with recessions and rapid changes in particular industries and occupations, as

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[9]John Williams, Booz Allen Hamilton, presentation to NRC Workshop on Meeting the Workforce Needs for the National Vision for Space Exploration, January 23, 2006.

[10]All three studies dealt with jobs for which U.S. citizens or permanent residents who were eligible to receive security clearances were required.

[11]Joan Burrelli, National Science Foundation, "NSF Studies of Enrollment and Graduation Trends," presentation to the NRC Workshop on Meeting the Workforce Needs for the National Vision for Space Exploration, January 23, 2006.

[12]Nick Terrell, Bureau of Labor Statistics, presentation to the Committee on Meeting the Workforce Needs for the National Vision for Space Exploration, Washington, D.C., February 22, 2006.

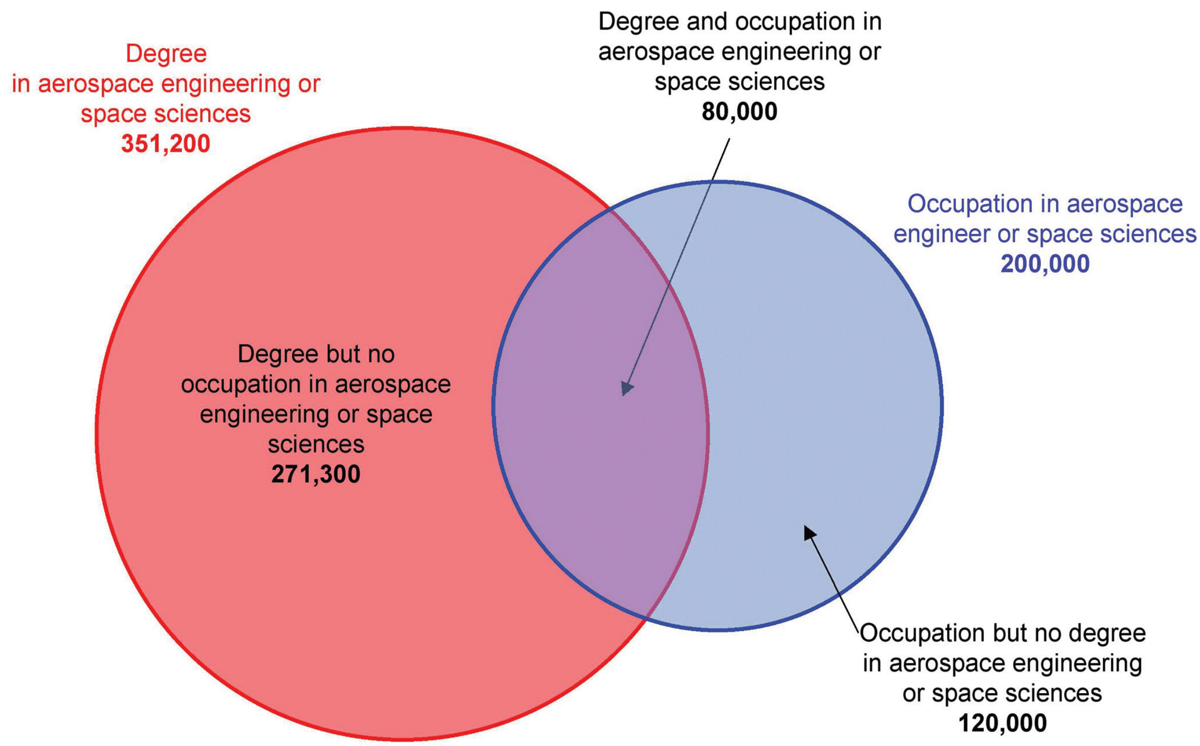

FIGURE 2.3 Degrees versus occupations in 2003, illustrating that people with specific degrees often work outside their areas. NOTE: Space sciences here include atmospheric sciences, physics, and astronomy. SOURCE: Courtesy of Joan Burrelli, NSF, "NSF Studies of Enrollment and Graduation Trends," presentation to NRC Workshop on Meeting the Workforce Needs for the National Vision for Space Exploration on January 23, 2006; data from the Scientists and Engineers Statistical Data System.

evidenced by projections for aerospace engineering for 1988 to 2000 that were unable to anticipate or take into account the industry's consolidation in the 1990s. Furthermore, in the BLS classification of occupations, all aerospace engineers are grouped together, and important specialties such as systems engineering are not identified at all. NASA's job definitions do not correspond with the standard occupational classifications produced by BLS, which lack sufficient detail to be useful for NASA planning. *A challenge to any attempt to understand and assess NASA's potential workforce problems—including this committee's attempt—is that it is difficult to compare the agency's demand for workers with the available supply as reflected in broad BLS occupational classifications.*

TRENDS IN UNIVERSITY ENROLLMENT AND DEGREES AWARDED

NASA draws its entry-level workers from the pool of recent recipients of the highest-level degrees in science and engineering disciplines. Over the past several years, increasing public attention has been paid to the question of whether the United States has the ability to produce an adequate supply of undergraduate and graduate students who can work in national security and aerospace, whose employees are predominantly U.S. citizens.

According to NSF data, the number of first-time, full-time graduate students enrolled in natural science and engineering fields grew slightly between 2000 and 2003 (the most recent period for which data are available). Despite the oft-stated concern in academia about a precipitous decline in applications from foreign students after 2001, increased graduate enrollment by U.S. citizens and permanent residents more than compensated for the

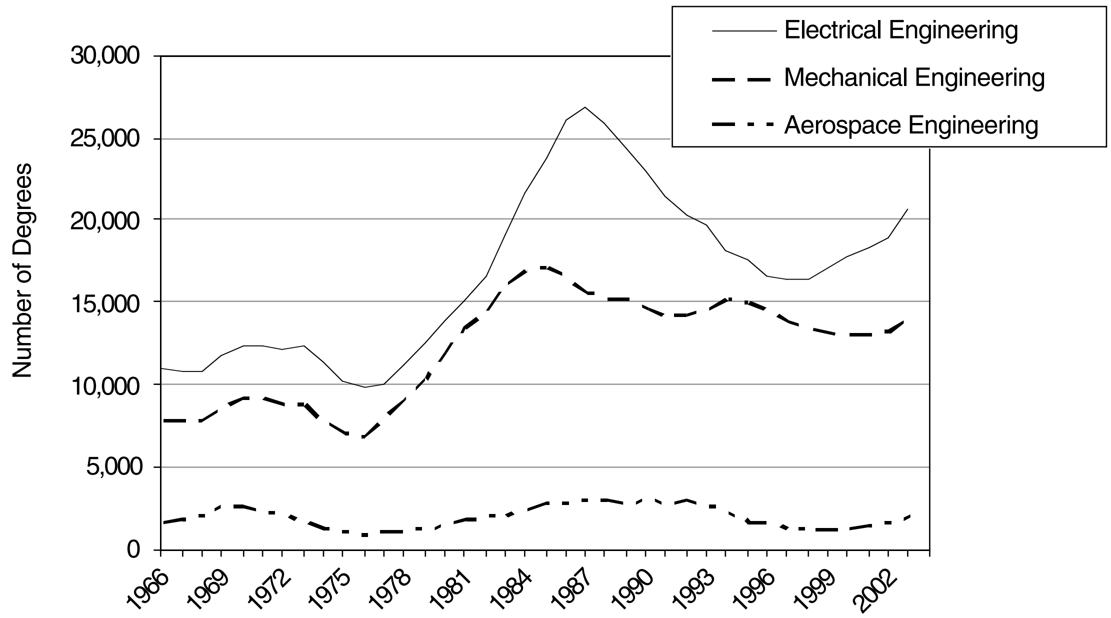

FIGURE 2.4 Aerospace engineering and space sciences degrees awarded, 1966-2003. NOTE: Space sciences here includes atmospheric sciences, physics, and astronomy. No data were available for 1999. SOURCE: Courtesy of Joan Burrelli, NSF, "NSF Studies of Enrollment and Graduation Trends," presentation to NRC Workshop on Meeting the Workforce Needs for the National Vision for Space Exploration on January 23, 2006; data from U.S. Department of Education, National Center for Education Statistics, IPEDS Completions Survey.

reduced numbers of foreign students. As with all natural science and engineering enrollment, first-time, full-time, graduate enrollment in aerospace engineering and space science mirrors unemployment trends (Figure 2.4).

NSF briefings to the committee indicated that aerospace engineering and space science graduate enrollments appear to have been less affected by visa issues than has enrollment as a whole for natural science and engineering. They also indicated that the aerospace and space science fields have experienced a relatively smaller drop in international students than has been the case for total natural science and engineering enrollments. Between 2000 and 2003, first-time graduate enrollment by U.S. citizens and permanent residents in aerospace engineering and space science grew. American Society for Engineering Education data show that the growth pattern in aerospace engineering continued in 2004 and 2005, both in numbers and as a fraction of total enrollees in all engineering fields.[13]

The "decline" in numbers of U.S. science and engineering students often cited in the press is not a true decline, but rather a relative decline reflecting primarily the massive growth of the student communities in developing nations such as China and India. The committee believes that this relative decline does not pose serious consequences for NASA's ability to attract and retain highly skilled personnel. Rather, the question is one of absolute numbers of available, highly skilled personnel.

During its various meetings, the committee heard from representatives of the DOD, major aerospace industries such as Boeing and Lockheed-Martin, the NSF, and the BLS. Although it acknowledges the difficulties in making labor market projections, the committee currently sees no evidence of a nationwide downturn in the supply of new talent in aerospace engineering and space sciences. The supply and the demand for new aerospace workers are

[13]American Society for Engineering Education (ASEE), *2005 Profiles of Engineering and Engineering Technology Colleges*, ASEE, Washington, D.C., 2006.

relatively well matched. However, the committee also notes that both NASA and the aerospace industry employ engineers from many different fields besides aerospace engineering, such as electrical engineering, making a comparison of supply and demand for NASA more complicated.

WORKFORCE DIVERSITY

During the 1990s, NASA made admirable efforts to diversify its workforce through programs such as the Minority University Research and Education Program (MUREP). The committee applauds this effort and believes that it must continue. If NASA and industry do not actively seek out employees from nontraditional demographic groups, they will miss out on the groups that are growing most rapidly in the United States, and their workforces will look less and less like the U.S. population as a whole.

Current demographic trends indicate that white males will constitute a smaller share of the labor market over time, primarily because of immigration. The Bureau of Labor Statistics projects that white males will constitute 34.9 percent of the total U.S. labor force in 2014 compared to 37.4 percent in 2004.[14] The divergent trends are more impressive if the growth rates are compared across demographic groups. Between 2004 and 2014, the number of white men in the labor force is projected to increase by 4.3 million (6.6 percent); in contrast, the number of women is projected to increase by 8.2 million (10.9 percent); of Blacks, by 1.3 million (16.8 percent); of Asians, by 2.0 million (32 percent); and of Hispanics, by 6.5 million (34 percent).

The nonprofit organization Engineers Dedicated to a Better Tomorrow analyzed data compiled by the NSF and the Department of Education to prepare a breakdown by gender of students earning bachelor's degrees in various fields of science and engineering.[15] The study identified four fields—physics, computer science, engineering, and engineering technology—as being behind all other science and engineering fields in terms of the gender diversity of their graduating baccalaureate classes. For those four fields taken together in 2004, only 21 percent of students earning baccalaureates were women, compared with 50 percent for science and engineering as a whole. The study noted that while the percentage of women earning baccalaureate degrees across all science and engineering fields has been rising steadily since the 1970s, the percentage of female degree earners has not increased significantly since 2000 for any of the four fields identified above.

Engineers Dedicated to a Better Tomorrow also examined the racial and ethnic makeup of students earning bachelor's degrees.[16] The overall percentage of baccalaureates in science and engineering awarded to underrepresented minorities in 2004 was just slightly below the corresponding college-wide percentage for all academic disciplines—16.4 versus 16.9 percent. For individual minority groups, the percentage of baccalaureates awarded in science and engineering versus all disciplines was approximately the same—8.4 versus 8.7 percent for Blacks, 7.3 versus 7.5 percent for Hispanics, and 0.71 versus 0.70 percent for Native Americans. The analysis found that three fields—physics, mathematics and statistics, and engineering—lagged significantly, both in 2004 and historically, in achieving racial/ethnic diversity in their graduating baccalaureate classes compared to the level seen for science and engineering as a whole. Blacks, Hispanics, and Native Americans were substantially underrepresented in physics, mathematics, and statistics; in engineering, Blacks and Native Americans were substantially underrepresented. This underrepresentation generally extended throughout the various subdisciplines of engineering.

The statistics on diversity are particularly significant given that NASA centers are located in states seeing major shifts in workforce diversity and college graduate diversity. For instance, the California Institute of Technology's Jet Propulsion Laboratory, NASA's Ames Research Center, Dryden Flight Research Center, Johnson Space Center, and Kennedy Space Center are all located in states with a Hispanic workforce and population demographic ranging

[14]All data in this paragraph are from Mitra Toossi, 2005, "Labor Force Projections to 2014: Retiring Boomers," *Monthly Labor Review*, November, Table 6, p. 39.

[15]Engineers Dedicated to a Better Tomorrow, "Women in Engineering and Related Fields—Diversity Analysis of Students Earning Bachelor's Degrees," *Dedicated Engineers Critical Issues Series*, Menlo Park, Calif., 2006, available at http://www.dedicatedengineers.org/news_pubs/Critical_Issues_Women_6-06.pdf.

[16]Engineers Dedicated to a Better Tomorrow, "Minorities in Engineering and Related Fields—Diversity Analysis of Students Earning Bachelor's Degrees," *Dedicated Engineers Critical Issues Series*, Menlo Park, Calif., 2006, available at http://www.dedicatedengineers.org/news_pubs/Critical_Issues_Minorities_6-06.pdf.

from 15 to 35 percent in the near term. NASA should pay attention and should nurture relationships and alliances with local and regional universities and with national student and professional organizations that are championing diversity opportunities nationwide.[17] The goal of the agency should be to ensure that, at the least, its recruiting reflects the trends in degree production for minority groups in the relevant disciplines, and at best exceeds them.

CONCLUSIONS

The committee drew several general conclusions from the data and perspectives summarized above:

1. Although there are currently some problems in meeting demand, particularly demand for workers with specific skills, the situation for major employers such as the DOD and the large aerospace companies is not now a major problem, based on evidence supplied by various industry and DOD experts at the committee's meetings.
2. Data on employment demand are difficult to obtain, particularly categorized by relevant skill areas, and those data and projections that exist are often ambiguous beyond the near term.
3. Most longer-term projections do forecast a gap between supply and demand that is larger than today's, but the size and the scope of the predicted gap are not clear.[18]
4. The problems with meeting future demand in the DOD are influenced by the need to employ principally U.S. citizens and permanent residents who can obtain security clearances.
5. In areas controlled by International Traffic in Arms Regulations (ITAR), NASA's workforce pool will be constrained.
6. NASA's employee age distribution is different from those of DOD and industry, both of which tend to be either bimodal or relatively flatter with age and thus more nearly like the age distribution of the U.S. workforce as a whole. The most important issue is the demographic trend at NASA whereby policy choices made during the last decade and a half have resulted in a steadily increasing average age of the agency's employees and fewer and fewer entry-level personnel capable of rising up through the agency's ranks to assume leadership positions in the future.
7. Skills are to some extent transferable, as demonstrated by the large numbers of engineers working in areas that they were not originally educated in—for instance, electrical engineers working in aerospace.

[17]Such societies include the American Indian Science and Engineering Society (AISES), the National Society of Black Engineers (NSBE), the Society for Advancement of Chicanos and Native Americans in Science (SACNAS), the Society of Hispanic Professional Engineers (SHPE), and the Society of Women Engineers (SWE).

[18]The Bureau of Labor Statistics does not forecast a shortage of aerospace engineers: its forecasts are for a supply that meets the market's requirements for workers. By contrast, industry forecasts are generally more pessimistic about the supply of engineers being adequate.

3

Skills Assessment and Workforce Strategy

NASA'S SEITT REPORT

Formed in 2005, NASA's Systems Engineering and Institutional Transition Team (SEITT) was charged with assessing the institutional implications of the agency's new plans for the Space Shuttle, the International Space Station, and the Constellation program, which encompasses the exploration systems architecture including development of the Orion spacecraft and the Ares launch vehicles. The SEITT was asked to make recommendations in four areas—human capital and workforce, organization and management, support requirements and contracts, and infrastructure. Portions of the final SEITT report were provided to the committee in early May 2006.[1]

The SEITT study addressed the longer-term skills that NASA will need for space exploration and other parts of NASA's mission. The study's goal was to discern trends in demands for skills based on the presumption that the evolution of programs in areas such as exploration and aeronautics might dramatically alter the types of skills needed by NASA, as well as the numbers and distribution of individuals with those skills.

The SEITT developed a spreadsheet listing 110 "workforce competencies" currently in the NASA workforce and defined in the agency's Competency Management System (see Appendix C).[2] It then worked through the headquarters mission directorate offices to characterize the relevance of each competency and chose a time designator (2005 to 2011, 2012 to 2018, beyond 2018) for when the competency might be needed, or trends might indicate when it would be needed. The team sought to identify groups of skill sets that would be needed by each NASA mission directorate for each of the three time periods. Its analysis focused on what skills would be needed, but not on the size of the workforce in competency areas. A key assumption of the SEITT's analysis was that there would be 10 "healthy" NASA field centers during this entire period.

The SEITT's overall conclusion was that too many unknowns existed at that time to develop firm strategies for workforce hiring. Among the uncertainties cited were expected but undefined changes in aeronautics programs, uncertain schedules for the Shuttle program, the effects of a NASA staff buyout conducted in the middle of the SEITT study, and the nature of the continuing development of the exploration program over the 15-year span of

[1]NASA, Office of Program Analysis and Evaluation, *Systems Engineering and Institutional Transitions Study, Final Report*, NASA, Washington, D.C., April 5, 2006.

[2]As defined in NASA's *National Aeronautics and Space Administration Workforce Strategy* (NASA, April 2006, p. 12, available at http://nasapeople.nasa.gov/HCM/WorkforceStrategy.pdf) and NASA's Competency Management System, a "competency" is "a conceptual representation of a body of knowledge. Competencies are used to categorize the capabilities of an employee, identify the knowledge requirements of a position or those associated with projects and programs, and forecast the agency's workforce requirements."

interest. Because the SEITT study was conducted primarily in late 2005 and early 2006, the committee is unsure about the degree to which these uncertainties remain as of spring 2007. Shuttle schedules and the effects of NASA's buyout program, for instance, should be known, but other uncertainties may have developed in the meantime.[3]

The SEITT found that 93 of the 110 separate competency areas were identified as being of primary importance by at least one of the four mission directorates, thereby accounting for nearly 99 percent of the agency's current workforce. Two skill areas—systems engineering and program/project management, which account for about 10 percent of the current workforce—were identified as being primary in all four directorates. Only 16 skill areas, covering only about 1.5 percent of the workforce, were not identified as primary for any directorate. The mission directorates did not identify any new skill areas for which there was not already some competency within NASA's current workforce.

In terms of general trends for future demand, the SEITT study found that nearly half the skill areas (41 percent) were likely to continue to have stable near-term (2006-2011) demand, nearly one-third (28 percent) were expected to be increasingly needed, and 16 percent were expected to experience diminished near-term demand. The study also uncovered skill areas, especially in the Space Operations Mission Directorate, for which the trend would be either increasing or decreasing demand in the near term and then would reverse in later years.

NASA's analysis concluded that as the Science Mission Directorate's (SMD's) programs steadily evolved, its demand for particular workforce skills would remain relatively unchanged and that the main task would be to recruit to fill vacancies created by normal attrition and to maintain an appropriate skill mix. The situation for the Space Operations Mission Directorate (SOMD) was more complex due to the combined impacts of the planned retirement of the Space Shuttle in 2010 and the onset of flight testing and, later, flight operations of new human exploration vehicles such as the Orion and the lunar lander. The SEITT identified 16 percent of SOMD civil service skill areas for which demand was expected to be reduced and 4 percent for which demand was expected to increase. It concluded that there would be decreasing demand in 40 percent of all SOMD contractor skill areas, and estimated that demand in remaining areas would remain stable.[4] For the Exploration Systems Mission Directorate (ESMD), the SEITT study found that modest near-term growth was expected in all skill areas traditionally identified with the design, development, and testing phases of programs.

The committee notes that the SEITT study did not include those important skills possessed by personnel in places like the Jet Propulsion Laboratory and the Johns Hopkins University's Applied Physics Laboratory Space Department that are also available to NASA. The committee was informed by NASA personnel that in the case of the Jet Propulsion Laboratory, such data existed but was difficult to obtain because JPL treats the information as proprietary. The committee believes that lack of such data limited the utility of the SEITT study.

NASA'S WORKFORCE STRATEGY

Drawing in part on the findings of the SEITT report, NASA's *Workforce Strategy*, a document that responds to a requirement in section 101(f) of the NASA Authorization Act of 2005 and was submitted to Congress on April 14, 2006, incorporates the agency's analysis of key workforce issues and information as of January 2006.[5]

The strategy cites the following important factors as shaping the environment to which NASA's planning must respond:

- Implementation of the 2004 Vision for Space Exploration,
- Retirement of the Space Shuttle by 2010,
- Refocusing of the aeronautics program on "long-term, cutting-edge, fundamental" research,
- Growing retirement-eligible fraction of the NASA workforce,

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[3]For example, in February 2007 NASA revealed that a lower than expected budget would result in slippage of the Orion and Ares I development schedules by 6 months.

[4]The SEITT report identified trends in the demand for contract workers only for SOMD programs whose overall workforce is 90 percent contract workers.

[5]NASA, *National Aeronautics and Space Administration Workforce Strategy*, April 2006, available at http://nasapeople.nasa.gov/HCM/WorkforceStrategy.pdf.

- Development of the Orion and Ares I, and
- NASA's move to full-cost management.

A key principle underlying the strategy is a commitment to build and maintain 10 healthy field centers. All centers are expected to have clear and stable roles and responsibilities, including major in-house spaceflight responsibility, to ensure that they all are fully engaged and productive. To ensure the workforce's flexibility in responding to both internal and external changes, the strategy indicates that NASA should move toward using a mix of permanent and non-permanent civil service personnel.

As indicated in the NASA document, the strategy is based on total NASA workforce projections that anticipate a budget-driven 10 percent decrease in the NASA workforce between 2006 and 2011, a reduction of nearly 2,000 personnel. The most significant changes described in the character of the work to be performed are for work in the ESMD and SOMD, where NASA anticipates transitioning from an operationally oriented workforce (as the Space Shuttle is retired) to one that is more focused on parallel development of the new Orion and Ares I launch vehicles, and then on developing new vehicles such as the lunar lander and Ares V rocket, and other systems required for the lunar outpost such as lunar rovers, as well as conducting spacecraft operations.

The pressures on NASA to manage its workforce while still preserving skills over time, within manpower ceilings, are amplified by events outside NASA's control, such as changes in the NASA budget compared with amounts assumed when Constellation program element schedules were developed. NASA's management efforts are also challenged by factors that are internal to NASA but are unquantifiable, such as the impact of development problems on schedules.

To enable NASA to prepare for its future workforce needs, especially to achieve the Vision for Space Exploration, the strategy assesses trends in the demand for future workforce competencies. The document summarizes the current extent of uncovered capacity (i.e., portions of the present workforce whose primary skills are not needed by the current program) and assesses both growing and diminishing competency needs for two time periods—2006 to 2009 and 2010 to 2011.

According to NASA, the immediate problem with employees whose primary skills are not currently needed is most significant at the three aeronautics centers (Ames, Glenn, and Langley). NASA identified an excess capacity in the areas of "engineering and science support (technicians), workforce operations and support; program/project management; computer science and information technology; space sciences; business operations; various systems engineering competencies; electrical and electronics systems; fundamental human factors research; and certain management competencies." The committee notes that as this study was being completed, NASA reported that the agency had significantly reduced its excess capacity problem. The committee notes that the recent reductions of excess personnel, in areas such as "program and project management" and "various systems engineering competencies," were primarily in aeronautics programs, not spaceflight programs.

NASA's *Workforce Strategy* describes a variety of approaches that NASA will use to meet its long-term needs for recruiting, retraining, and sustaining its workforce. Identified recruitment tools include targeted programs (e.g., co-op student programs, internships, Presidential Management Fellows Program), streamlined hiring authorities and special incentives available through recent legislative authority, and NASA-sponsored education programs. Retention tools include nurturing NASA's reputation as one of the best places in the federal government to work, pursuing the strategy of building and engaging all 10 NASA centers, establishing an agency-wide career development program to foster lifelong learning, and using a number of targeted incentives (e.g., pay and relocation incentives, pay enhancements for exceptional candidates in critical positions, and Intergovernmental Personnel Act assignments).

The strategy also considers steps that the agency should take to respond to inevitable attrition, including retirements. These steps include the possibility of offering retirees who have critical skills post-retirement employment without the loss of annuity payments, as well as programs designed to transfer expertise from senior employees to less highly skilled employees by methods such as mentoring programs. NASA officials indicated to the committee that two related documents—a mission support implementation plan and a workforce implementation plan—are being developed by NASA to identify specific actions to be taken to implement the strategy.

NASA MAKE-OR-BUY DECISIONS

NASA administrator Griffin has stated publicly that one of his goals is to rebuild NASA's in-house technical capability.[6] The SEITT report, in agreement with a major conclusion of a 1991 National Academy of Public Administration report, noted that the determination of whether to conduct work in-house (make) or to acquire work from outside contractors (buy) would be a major factor in improving NASA's ability to execute missions, improve its performance, and foster its institutional capability.[7]

NASA does not currently have a formal, systematic process for make-or-buy decision making or for optimizing the impacts of such decisions on institutional objectives. The SEITT report recommended that the Office of the Chief Engineer develop guidelines for make-or-buy analyses and that the agency's senior management put in place a formal process for make-or-buy decision making for all major projects. Factors to be considered, according to the SEITT report, include organizational sustainability; appropriate government management of high-risk programs and projects; alignment of work assignments with in-house core capabilities and capacity; impacts associated with workforce, contracts, infrastructure, systems engineering, and integration; and agency-wide strategic optimization for mission performance.

NASA'S IN-HOUSE SCIENCE STAFF

Whereas make-or-buy decisions primarily affect NASA's engineering and program management requirements, a similar concern involves the agency's in-house science staff. Approximately 12 percent of the full-time science and engineering employees at NASA, or ~1,200 individuals, are scientists.[8] Although not a large number compared with NASA's overall workforce, it equals a large fraction of the level of workforce reduction being considered over the next 5 years. The committee therefore considered that it was necessary to discuss the in-house science staff.

The work of NASA scientists is unique in accomplishing the agency's mission of expanding human knowledge through space-based exploration. They provide a critical interface between the science community and the NASA engineers and managers who implement NASA missions, maintaining stewardship of the community's science priorities and ensuring that those priorities are held front and center in the execution of NASA scientific flight missions. NASA scientists also serve the broader science community through participation in the celestial navigation experience base maintained at the Jet Propulsion Laboratory, which is vital for supporting other NASA projects; the lunar sample curatorial facility in Houston; the National Space Science Data Center at Goddard Space Flight Center; and the microgravity drop tower facility at Glenn Research Center. In-house scientists also play key roles in focused R&D programs and shepherd technology development partnerships with academia and industry that enable future missions.

The roles NASA scientists play span all three phases of the exploration cycle: (1) the pre-formulation phase, during which they interface with the science community to ensure that high-priority future science goals are the focus of basic research, technology development, and mission concept development efforts; (2) the project development phase, when they serve as project and instrument scientists, among other roles, ensuring that mission science requirements are implemented to the fullest extent possible and engaging the science community in the process of implementing NASA missions; and (3) the mission operations/data analysis phase, when they continue to serve as project scientists and also are often responsible for administering the observing and guest investigator proposal review process and ensuring that data are calibrated, distributed to the science community, and archived for external use.

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[6]Griffin said, "As a central organizing principle of our work, and despite the fact that 80 percent of our total funding goes to industry and will continue to do so, I firmly believe that it must be NASA and its engineering staff, and not our contractors, who will assume the primary responsibility for making this program work." Michael Griffin, remarks at National Society of Professional Engineers Professional Development Conference, Washington, D.C., January 19, 2006.

[7]National Academy of Public Administration (NAPA), *Maintaining the Program Balance*, NAPA, Washington, D.C., January 1991.

[8]NASA has 10,046 science and engineering employees out of a total of 16,745 full-time permanent employees. NASA has more than 18,000 total full-time employees, but not all of these are permanent. The number of scientists, which includes groups that were "scientific staff" (not clerical/admin or health/medical/hospital/dental), is approximately 1,150 (or 11.7 percent). This number includes mathematics. Without mathematics, the number is approximately 960 (9.6 percent). See http://naade02.msfc.nasa.gov/workforce/.

Just as NASA engineers and managers must be able to acquire and continue to improve their core capabilities and maintain their technical capabilities through hands-on experience, so also must scientists maintain a presence in the science community as practicing scientists to continue to perform their duties. This work as practicing scientists, i.e., basic research, is typically done during the first and third phases of the exploration cycle outlined above—the pre-formulation phase often entails basic R&D, and data analysis is fundamentally a scientific research activity. The key is that this work is best performed within the context of a NASA scientist's job to interface with the broader community and provide stewardship of community priorities within the agency. Neglecting the basic research role of NASA scientists would lead to an unhealthy NASA scientific workforce, ultimately weakening the agency's ability to execute national science priorities.

As a result of the transition to full-cost accounting (now called full-cost management), much of the "practicing science" work at NASA centers is now funded through the research and analysis programs, which have limited budgets. NASA scientists are thus in direct competition with the broader science community (in addition to working with it, as their roles intend). The committee was not presented with data regarding the extent to which the level of funding that was transferred to the research and analysis accounts during the transition to full-cost accounting was adequate to cover the work of in-house scientists. Anecdotal evidence from NASA in-house scientists and from research and analysis peer review panels suggests that the transferred funds were inadequate. Currently, some of the NASA center scientists are partially or fully unfunded with regard to their "practicing science" work, and have thus in many cases been at a disadvantage in proposal competitions.

The committee supports the continuation of the community service role for NASA scientists, whereby, for example, the individual works in support of a project that benefits the entire science community rather than his or her own research. The committee does, however, urge NASA to develop a formal position regarding the in-house scientific staff as an element of the agency's workforce strategy. As input for its policy, NASA should assess whether the number of in-house scientists is at the appropriate level. Such an assessment could lead to conclusions that the size and skill mix of the in-house cadre at a particular center might need to increase or to decrease. However, as NASA reshapes its workforce in the context of the Vision for Space Exploration, it is critical to maintain in-house scientific competence to provide scientific leadership and to maintain expertise in specialty areas that are not broadly practiced in universities and industry.

In the context of the aerospace workforce ecosystem construct mentioned below in this chapter, NASA might consider ways in which scientists engaged in their "practicing research" but not playing key roles in a current project might better reside in academia as research faculty. This approach would capture the need for keeping the in-house science staff "fresh," as well as providing flexibility and mobility akin to that which the committee has advocated for engineering staff.

COMMITTEE ASSESSMENT OF WORKFORCE NEEDS

The committee believes that through the work of the SEITT and in NASA's 2006 *Workforce Strategy*, NASA has made a reasonable start at a top-down assessment of its future workforce needs, but that this process must continue in order to be useful to the agency. The committee also concluded that because the assessment was top-down—that is, conducted by the headquarters mission directorates and not the NASA centers—NASA will not understand the true capability of the existing workforce and/or staffing requirements until a more in-depth bottom-up assessment (i.e., one conducted by the NASA centers) is completed and a strategic workforce demand and development model is prepared.

Based on its own assessment of NASA work as described both in the SEITT report and in presentations to the committee made by agency representatives and some of its key contractors, the committee is concerned about three specific areas. The first, which is clearly recognized by NASA, is the lack of highly skilled personnel with expertise in program/project management and systems engineering, and current experience in the development of large human spaceflight systems. This issue is addressed in the next chapter. The second area of concern to the committee is that NASA has not conducted center-specific analyses of its current workforce. The third concern is that NASA has not developed specific numbers for the competencies needed, nor has it aggregated the competency needs into actual job requirements by center and over time.

Finally, the committee believes that NASA must make a formal assessment of its needs for in-house scientists at its individual centers and determine if they are at the right level.

Finding 1: NASA has undertaken a commendable top-down (i.e., headquarters-directed) analysis of current agency needs and the skill levels of its current workforce that the committee believes is an excellent first step. But although NASA has considered workforce needs for the agency as a whole, it has not yet projected its requirements for future hiring in terms of (1) the numbers and specific skill sets of workers expected to be needed by each NASA center over time and (2) the timeframes for hiring based on anticipated retirements of the present workforce. The committee believes that understanding future hiring requirements will depend on an accurate, detailed assessment of the skills, VSE-related development capabilities, and expected attrition of the workforce for each center.

Recommendation 1: Collect detailed data on NASA workforce requirements.

The committee recommends that NASA collect detailed data on and develop accurate assessments of the capabilities possessed by the current workforce and required for the future S&T workforce.

- **Because each NASA center has unique mission requirements and the mobility of personnel between centers is limited, NASA should complete a center-developed, bottom-up assessment of the current skills, experience levels, and projected attrition of the workforce for each individual NASA center.**
- **NASA should use the data obtained from such assessments to develop a model for projecting future NASA priorities for VSE skill development and hiring by competencies, experience levels, and centers, as well as a model for the best mix of skill development conducted within NASA versus within industry.**
- **NASA should translate identified workforce needs from competencies and experience levels into specific positions to be implemented at individual centers at specific points in time.**
- **NASA should assess whether the skill levels of in-house scientists at each field center are appropriate to fulfilling that center's scientific leadership and service responsibilities and should ensure that appropriate efforts are made to maintain the scientific competency and currency of each center's scientific workforce.**
- **NASA should ensure that hiring constraints—such as pay levels, personnel ceilings, and ability to recruit suitable candidates—guide make-or-buy decisions about how staffing needs will be met.**
- **NASA should ensure that appropriate workforce strategies—including providing training for staff (e.g., through the NASA Academy of Program/Project and Engineering Leadership program), contracting out work to industry and academia, facilitating exchange programs, and hiring temporary contract and term employees—are applied at each center.**

The committee believes that it is premature to recommend a particular mix of strategies for obtaining the desired worker skill mix until NASA fully defines its staffing needs.

Finding 2: In the short term, NASA has too few program/project managers and systems engineers with the requisite experience in human spaceflight systems development to successfully oversee VSE projects. Given the lack of detailed data on NASA's near-term workforce skills and needs as well as uncertainties over NASA's budget, the committee did not attempt to assess the likely success of NASA's planned steps to address near-term workforce problems.

The committee concluded that there is no major nationwide shortfall in the supply of eligible aerospace workers in the short term. The 250-350 skilled program/project managers and systems engineers that NASA estimates it requires for its human spaceflight program are only a relatively small fraction of the overall U.S. aerospace workforce. However, the committee is concerned about the possibility of insufficient recent entry-level workers (i.e., in the 25-29 year age band) currently at NASA. Policy decisions made by NASA in the 1990s resulted in the agency hiring fewer younger workers and helped contribute to a situation whereby the overall age of NASA's internal workforce has been steadily increasing for more than a decade. The committee is concerned that NASA may not have sufficient in-house personnel capable of rising through the agency ranks and acquiring the experience that will be required in the next decades to implement the Vision for Space Exploration.

Recommendation 2: Hire and retain younger workers within NASA.

The committee recommends that NASA implement a long-term strategy for hiring a steady supply of younger workers and subsequently retaining those workers as they rise to senior management positions so that a balanced distribution of age and skill is maintained throughout the agency's entire workforce.

- **NASA should take full advantage of the NASA Flexibility Act of 2004, which was passed to facilitate the agency's recruitment of employees from industry. NASA has already utilized the act to a considerable extent, and the committee encourages the agency to continue to do so, as well as to inform Congress of any additional hiring flexibility that is required.**
- **NASA, working with Congress and the executive branch, should develop solutions to legal problems that limit the flow of senior and highly skilled employees from industry to NASA even when such employees are willing to accept lower salaries. Issues regarding shareholding, pensions, and perceived or actual conflicts of interest severely hamper personnel exchanges between industry and NASA. These problems stem from policy issues that cannot be resolved by NASA alone but instead require action by Congress and the executive branch working in concert with NASA.**

THE AEROSPACE WORKFORCE ECOSYSTEM

NASA has several options for filling required skill areas in order to accomplish the Vision for Space Exploration. These include transferring personnel within the agency (such as from the Shuttle and International Space Station programs to the Constellation program), retraining personnel, or hiring from industry. To meet short-term needs (i.e., through 2011), training and retraining have limited ability to fill any gaps in highly skilled personnel. The committee believes that with a proper emphasis on training and on recruiting new hires, NASA could be in a position between 2012 and 2018 to have enough skilled personnel in areas key to implementation of the VSE. That said, however, it became clear to the committee during its fact finding and deliberations that only by tapping into the workforce that currently resides in industry, academia, and other government agencies can NASA obtain the skills required between now and 2012.

The committee believes that it is necessary to consider NASA's workforce issues in the broader context of an aerospace workforce ecosystem. The essence of an ecosystem is that its elements work together synergistically, adapting to environmental stresses to maintain the ecosystem's key elements. Viewed from the perspective of the aerospace workforce, the dominant components of the aerospace workforce ecosystem are DOD, industry, academia, and NASA (Figure 3.1). In terms of the size of its science and engineering workforce, NASA is the smallest member of the ecosystem. This fact alone strongly suggests that an optimal solution to NASA's workforce issues is not to be found by considering NASA in isolation from the rest of the aerospace ecosystem.

Input to the committee from NASA, DOD, industry, and university representatives indicated clearly that there are aerospace workforce issues in common among them, as well as interconnections that are either central to, or strongly affected by, actions taken by one or more of these groups. For example, NASA and DOD presentations to the committee emphasized the need for highly skilled systems engineers and project managers. These skills have critical value for industry as well. As with any ecosystem, tensions can arise within the system because of competition for resources. In any ecosystem, the successful elements are able to deal with competition, often by forming strategic partnerships as well as by carefully aligning resources. This attribute becomes particularly important if the ecosystem is operating in an environment of stress, such as limited resources (funding). The evidence strongly suggests that this is a time of substantial fiscal stress for NASA in terms of implementing the VSE.

Each element of the aerospace ecosystem has a primary traditional mission as an organization that can contribute to NASA's realization of the VSE. However, each may also face competitive challenges in certain situations that must be considered. For instance, an aerospace company may have both a DOD and a NASA contract proposal to develop, and depending on a variety of circumstances, one may be more attractive to pursue than the other. All four constituents of the aerospace ecosystem are continually competing for talent and technology to get their respective jobs accomplished.

The ultimate success of any ecosystem is its ability to achieve a dynamic balance between the external environment and the elements of the system. An important facet of the elements of the aerospace workforce ecosystem is

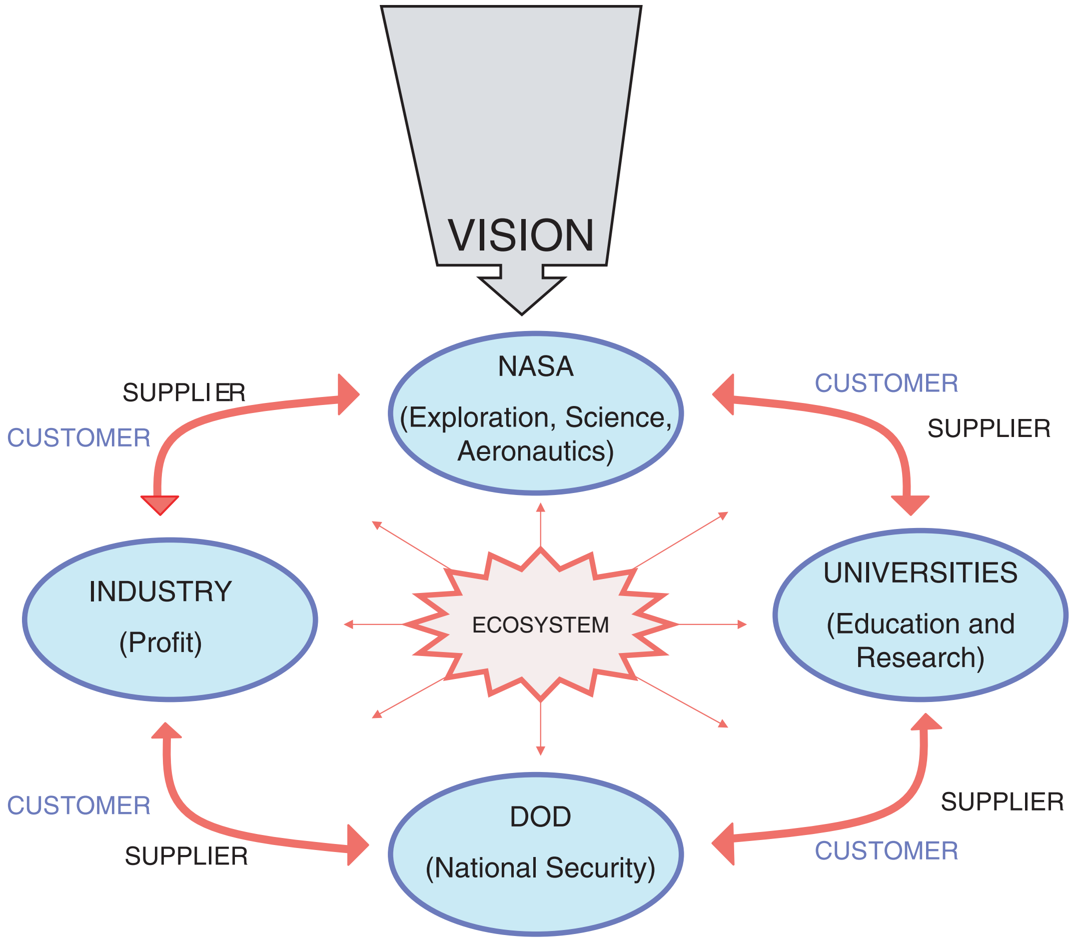

FIGURE 3.1 The aerospace workforce ecosystem.

that significantly different time horizons dominate their planning and activity. Recognition of these differences is essential to an informed discussion of the aerospace workforce for any element in the aerospace ecosystem.

The aerospace workforce ecosystem must also be viewed in the context of various externalities. These could include federal policies relative to International Traffic in Arms Regulations (ITAR), legislative funding changes as well as shifts in administration policies regarding civilian space priorities, and opportunities presented by other agencies such as NSF with significant funding targeted for university programs. Despite evidence that the number of foreign students enrolled in U.S. universities has not diminished substantially in recent years, ITAR has affected the availability of these students for involvement in certain elements of the aerospace ecosystem.

It is apparent to the committee that a broad perspective is the best one from which to assess and address NASA's workforce issues. This does not in any way diminish the value of key training and hiring for the future, but those activities should also be informed by what is taking place in the broader national aerospace workforce.

The committee notes that the national space policy released by the White House in early October 2006 also emphasized the importance of a skilled workforce for the overall U.S. space effort, stating: "Sustained excellence in space-related science, engineering, acquisition, and operational disciplines is vital to the future of U.S. space capabilities. Departments and agencies that conduct space related activities shall establish standards and implement activities to develop and maintain highly skilled, experienced, and motivated space professionals within their workforce."[9]

Given the wide range of attributes that characterize the elements of the aerospace workforce ecosystem depicted in Figure 3.1, the differing elements' time horizons and missions, and the interconnectedness of those elements, the committee concluded that resolving NASA's workforce issues is a task that is beyond NASA alone: it is national in character and as such requires a broad, collaborative strategy, as well as policy coordination at a high level.

As the committee was finishing its work, Congress passed the Interagency Aerospace Workforce Revitalization Task Force Act,[10] whose purpose is to establish an interagency aerospace revitalization task force to "develop a national strategy for aerospace workforce recruitment, training, and cultivation." The committee believes that this act is a good first step but is concerned that the task force may be a one-time activity and believes that the aerospace workforce ecosystem requires long-term attention.

Finding 3: NASA's workforce requirements and challenges cannot be considered in isolation from those of other government and industry organizations. NASA is part of an aerospace workforce ecosystem in which the health and needs of one organization or sector can affect another. Thus, NASA's workforce issues require the intervention and assistance of higher-level government organizations such as the Office of Science and Technology Policy in the Executive Office of the President.

Recommendation 3: Ensure a coordinated national strategy for aerospace workforce development among relevant institutions.

The committee recommends that representatives from relevant government agencies, the aerospace industry, including the emerging private sector, and the academic community work together to develop a coordinated national strategy to ensure an effective aerospace workforce ecosystem.

The committee urges the Office of Science and Technology Policy to include representatives of the broad interests of all components of the aerospace workforce ecosystem in the development of an effective national strategy. This representation should be from organizations that can reflect the broad interests of the various components of the ecosystem, as distinct from individual companies or universities. For example, DOD could be represented by the Defense Directorate of Research and Engineering, and NASA by the deputy administrator. The committee urges that the strategy set a series of 5-year horizons for addressing, among other issues, issues of the supply pipeline, retirement, and diversity, along with ITAR and related citizenship-related issues.

[9]See Office of Science and Technology Policy, "U.S. National Space Policy," 2006, available at http://www.ostp.gov/html/US%20National%20Space%20Policy.pdf.

[10]See http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=109_cong_public_laws&docid=f:publ420.109.

4

The Vital Role of Program/Project Management and Systems Engineering at NASA

Given the size, complexity, and number of parallel system developments required in both the near and the long term, achieving the goals of the Vision for Space Exploration (VSE) would be extremely challenging even under ideal circumstances. However, requirements for personnel with specific skills and expertise, such as experienced program/project managers and systems engineers, in NASA's workforce will make the VSE an even more ambitious undertaking.

NASA PROGRAM MANAGEMENT AND SYSTEMS ENGINEERING

NASA's SEITT report stated that the agency's development of a space exploration architecture raises several major concerns, among them "the availability of sufficient expertise in the management of large space development programs."[1] More specifically, the agency's April 2006 *Workforce Strategy* discussed agency workforce competency trends. Section 3C of that assessment identified an increased need through fiscal year 2009 in five skill areas: program/project management, systems engineering and integration engineering, mission operations competencies, systems analysis and mission planning, and quality/safety/performance.[2] NASA identified a requirement for the following number of full-time employees with the competencies indicated:

- 150-200 with program/project management competency;
- 100-150 with systems engineering and integration engineering competency;
- 200-240 with mission operations competencies;
- 25-40 with systems analysis and mission planning competency; and
- 50-75 with quality/safety/performance competency.

Thus, the agency requires 525 to 705 personnel in these areas, a requirement driven primarily by the establishment of the Constellation program. Several of these skill areas are particularly challenging to fill because they

[1]NASA, Office of Program Analysis and Evaluation, *Systems Engineering and Institutional Transitions Study, Final Report*, April 5, 2006, p. 13.

[2]NASA, *National Aeronautics and Space Administration Workforce Strategy*, April 2006, pp. 15-16, available at http://nasapeople.nasa.gov/HCM/WorkforceStrategy.pdf.

are heavily experience-based, with competence developed as a result of involvement over many years in many projects.

Although the mission operations competencies category is the largest, the committee notes that this competency is relatively easier to fill from NASA's existing workforce because the agency already conducts mission operations in both the Space Shuttle and the International Space Station programs. In contrast, in the competency areas of program/project management and systems engineering and integration engineering (with a requirement for 250-350 full-time employees), the agency is at a greater disadvantage because it has not conducted significant development of human spaceflight systems in-house in nearly three decades.

Not since the design of the Space Shuttle has there been such a demand or opportunity for the development of major human spaceflight systems. NASA's most recent human spaceflight development project, the International Space Station, engaged a primary contractor as the systems engineering and integration lead and provided only a limited number of systems engineering and program management learning opportunities for NASA's workforce, which concentrated on the operational aspects of ISS such as pre-launch integration testing, on-orbit assembly, and flight operations.

To fulfill requirements for expertise in program/project management and systems engineering and integration engineering, NASA will thus be forced either to recruit highly skilled personnel from industry or to use personnel who have less experience than it might desire. The committee heard evidence that the agency has taken both of these approaches.

The committee believes that highly skilled personnel in these categories are key to the successful conduct of projects. As noted in a 2003 Department of Defense report on the acquisition of national security space programs, inadequate systems engineering in the early design and definition stages of a project has historically been the cause of major program technical, cost, and schedule problems (see Box 4.1).[3]

Other government agencies with missions similar to NASA's, such as the U.S. Air Force and the National Reconnaissance Office, have also recognized the importance of highly skilled systems engineers as well as the difficulties of developing and maintaining them.[4] Based on previous studies conducted for those organizations as well as comments made to the committee during its meetings, the committee concluded that skilled program managers and highly skilled systems engineers are a vital resource.[5]

The industry-wide requirement for highly skilled program managers and systems engineers is not new; on the contrary, it has been recognized as a problem within the aerospace industry for at least 20 years. Rather than an acute crisis, the requirement thus remains an ongoing challenge. In NASA's case and for human spaceflight in particular, the challenge is more formidable because of the lack of recent large human spaceflight technology development programs, constrained hiring as a result of the downsizing in the 1990s, and the prospective workforce's skepticism about whether NASA can offer a long-term commitment to providing challenging work at competitive salaries that will survive a given presidential administration.

The committee notes that identification by NASA, industry, and the national security space establishment of the requirement for skilled program/project management and systems engineers not only underscores the importance of these skill areas, but also highlights the difficulty that NASA faces in obtaining them—the agency must compete with industry and DOD for employees that those sectors also value highly.

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[3]Department of Defense (DOD), Report of the Defense Science board/Air Force Scientific Advisory Board Joint Task Force on Acquisition of National Security Space Programs, Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, DOD, Washington, D.C., 2003.

[4]During presentations before the Air Force Studies Board in January 2007, several Air Force and NRO officials spoke about the difficulties of conducting systems engineering for national security space programs. The presenters included Roberta M. Ewart, "The Counterspace Architecting Process: Briefing to the National Research Council," January 9, 2007; Colonel James Horejsi, "Applying Systems Engineering to Pre-Milestone A Activities," January 8, 2007; and Major General Mark Shackelford, "Thoughts on Systems Engineering," January 8, 2007. The Air Force in particular faces difficulties in maintaining these skills in-house and has lost many of them to industry.

[5]Gen. Thomas S. Moorman, Jr., U.S. Air Force (retired), testimony before the House Subcommittee on Space and Aeronautics, May 15, 2001; John Williams, Booz Allen Hamilton, presentation to NRC Workshop on Meeting the Workforce Needs for the National Vision for Space Exploration, January 23, 2006; Report of the Defense Science Board/Air Force Scientific Advisory Board Joint Task Force on Acquisition of National Security Space Programs, May 2003, Office of the Undersecretary of Defense for Acquisition, Technology, and Logistics, available at http://www.acq.osd.mil/dsb/reports/space.pdf.

BOX 4.1
Common Factors Contributing to the Success or Failure of NASA Programs

Factors contributing to program failures or significant cost growth (from investigations)

- Inadequate requirements management
- Convoluted board/panel processes
- Poor systems engineering processes
- Inadequate reviews/oversight
- Inadequate heritage design analyses in early phases
- Inadequate systems engineering and integration expertise
- Inadequate testing/interpretation of test data
- Inadequate systems-level risk management

Contributing factors associated with successful programs (from organizational literature)

- Rigorous requirements management
- Rigorous interface control/streamlined boards and panels
- Rigorous systems engineering processes/reviews
- Strong government/contractor teaming
- Experienced personnel
- Thorough testing
- Systems level approach throughout program levels
- Rigorous risk management

SOURCE: Adapted from NASA, Office of Program Analysis and Evaluation, *Systems Engineering and Institutional Transitions Study, Final Report*, April 5, 2006.

In considering whether NASA also faces a requirement for highly skilled systems engineering and program/project management personnel in its robotic spaceflight program, the committee found that a steady succession of robotic programs has provided opportunities for sustaining a base of expertise in NASA and industry in robotic spaceflight. Nevertheless, given the concerns it heard expressed within NASA, academia, and industry about the amount of experience within the program/project management and systems engineering base in the robotic spaceflight program, the committee concluded that these concerns apply to *both* the human spacecraft and the robotic spaceflight programs at NASA.[6]

The committee struggled with the question of whether the requirement for 250-350 highly skilled program/project managers and systems and integration engineers in the short term constituted a shortfall in NASA's workforce. The problem for the committee was that the numbers presented by NASA in its *Workforce Strategy* did not indicate the amount of experience desired by the agency for each of the positions.

INDUSTRY PERSPECTIVE

To gain a perspective on this issue, the committee sought input from an industry consortium. A sampling of representatives of 25 member companies of the Aerospace Industries Association (AIA) expressed specific concerns regarding NASA's systems engineering and program management experience, the fact that many NASA engineers

[6]For example, the 2006 NRC report *Assessment of Balance in NASA's Science Programs* (The National Academies Press, Washington, D.C.) made a major point about problems with program execution in NASA's Science Mission Directorate and attributed these problems, in part, to the adequacy of staff.

TABLE 4.1 Short- and Long-term Challenges in Attracting Properly Skilled Aerospace Workers, as Identified by AIA Industry Representatives

	Challenges	
	NASA	Industry
Short term	• Competing for available talent • Maintaining the current workforce until new talent is recruited and trained • Training and transferring workers and skill sets to support NASA priorities • Addressing the mismatch between the skills needed for R&D and for operations	• Adequate federal funding and a stable Vision architecture • Workforce compensation • NASA's ability to maintain a skilled workforce in a high-risk environment • NASA's need to bring in a workforce dedicated to innovation
Long term	• Insufficient lead times for contractors and subcontractors that do not allow the appropriate skill sets to be in place • NASA projects that can involve very large industry investment but that can face sudden termination • Canceled jobs that lead to attrition to other industry (non-aerospace) projects	• Investment uncertainty if administration, congressional, and NASA support of the Vision for Space Exploration is lacking • Impact of International Traffic in Arms Regulations (ITAR) regulations that hamper U.S. companies possessing a multinational workforce

do not have program start-up experience, and the risk that delays in the Orion program would likely increase attrition if its workers chose to leave NASA to work on more active projects in industry. For the longer term, i.e., after Orion development, there was concern about a lack of appropriately experienced engineers at NASA and NASA's ability to compete with compensation levels in industry at the more senior levels.

Although there was a sense among the industry representatives sampled that the needed workforce was currently available in industry, there was nevertheless concern that industry also probably lacks depth in some key skill areas. Industry was seen as having an advantage in being able to move workers between the national security, civil government, and commercial sectors to meet varying needs. For the longer term, industry representatives indicated that meeting workforce needs will be influenced by whether the Vision for Space Exploration is compelling and its funding stable enough to attract young workers and minimize attrition rates.

The AIA group of aerospace industry representatives who provided input to the committee identified the challenges for NASA and industry outlined in Table 4.1.

NASA RECRUITING CHALLENGES

In the near term, NASA is pursuing the hiring of relatively senior aerospace industry personnel—and in some cases DOD personnel—to address its shortfall of highly skilled large-program managers and systems engineers. Several challenges face NASA in its recruitment of senior personnel, including competition with industry for the same skills; NASA's inability to pay competitive salaries at the senior levels; uncertainty over continued political and funding support for the Vision for Space Exploration; and conflict-of-interest limitations on flexibility in assignments for senior managers recruited from the aerospace industry.

Although NASA's pay scale is competitive with industry's at the entry and middle levels, industry senior-level compensation packages, including recruitment bonuses, far exceed federal government pay scales. Congress responded by approving the NASA Flexibility Act of 2004, which provided for expansion of NASA's authority to offer employee recruitment and retention bonuses. The committee believes that the act has helped but that NASA has not yet taken full advantage of it, and the committee encourages NASA to continue to exploit the act to its fullest limits. The committee believes, however, that the act cannot completely alleviate many of the difficulties apparent when all senior government positions are compared with equivalent positions in industry, such as stock and retirement packages for senior executives in industry that can range into the tens of millions of dollars.

Historically, NASA's exciting mission has provided the best competitive edge for NASA's ability to attract senior personnel. Given the pressures on NASA's budget, the perceived threat to the sustainability of the VSE programs at meaningful levels through the next presidential election, and the attendant risk to an individual employee of leaving a secure position in an aerospace company with a broader variety of challenging programs, participation in NASA missions is not the attraction it once was, especially for senior-level personnel.

Shifts over the past 25 years in pension programs, from defined-benefit plans that encourage and reward long-term service to 401k pension programs that are portable, tend to tie workers, including federal government workers, less to a single employer. Moreover, in industry the provision of matching stock in 401k programs and employee bonuses in the form of stock options to senior personnel who possess 20-25 years of experience has meant that senior aerospace company program managers and systems engineers who are recruited into the federal government are limited in terms of allowable contractual and technical decision making and oversight roles for projects involving their former company. Given that there are now only three major human spaceflight contractors, this limitation affects NASA's flexibility in using senior-level industry employees.

NASA'S IN-HOUSE PROJECT MANAGEMENT AND SYSTEMS ENGINEERING TRAINING PROGRAM

Neither NASA nor U.S. industry has in recent decades undertaken a human space system development program of the magnitude and breadth required for implementing the Vision for Space Exploration. Earlier large programs—Mercury, Gemini, Apollo, the Space Shuttle—accomplished more than each program's immediate task by providing vital training and experience for NASA's workforce. Although a more recent program, the ISS posed fewer high-risk technology challenges than those faced by earlier large programs, and it therefore depended more heavily on the contractor workforce for systems development, with the NASA workforce concentrating on the operational aspects of the program and thus having fewer hands-on development training opportunities. Having focused on different programs since the development of the shuttle was completed, NASA must now rely on coursework and virtual training programs to give personnel critical exposure to systems engineering and program management for human spaceflight systems.

NASA's principal in-house training programs for project management and systems engineering are managed by the agency's Academy of Program/Project and Engineering Leadership (APPEL) in the Office of the Chief Engineer.[7,8] APPEL supports curriculum development and classroom training, providing a variety of opportunities that include retreat-style workshops lasting 1 or 2 days, in-house courses that last several weeks, and residential coursework at universities; knowledge sharing through agency publications and workshops utilizing highly skilled NASA practitioners and outside experts; independent assessments and consultations for projects, teams, and individuals; and applied research to develop advanced project management concepts relevant to NASA's needs. APPEL also coordinates the annual Project Management Challenge event, which in 2006 attracted nearly 1,000 participants from NASA, industry, and academia. The conference is supported by the online magazine *PM Perspectives*.[9] However, according to the experience of committee members, the program has been criticized for the lack of direct incentives for participation.

APPEL's coursework strongly emphasizes case studies, including online video, audio, and interactive demonstrations.[10] However, this set of case studies lacks any large human spaceflight systems examples. Although

[7]See http://appel.nasa.gov/.

[8]In the late 1980s, NASA created the Program and Project Management Initiative (PPMI), a small office charged with providing coursework meant to promote project management excellence. The effort remained small for much of its history, often operating with only one full-time employee. At the time, NASA considered program management a skill adequately taught by NASA's slate of active missions, and it placed little emphasis on the program: "The initial PPMI curriculum efforts were limited in scope to traditional training approaches, reflecting the status of Adult Learning theory and technology at the time. . . . In this era of a few very large programs, with an abundance of project expertise cultivated through the challenges of Apollo and Shuttle, such a strategy was both logical and desirable." See http://appel.nasa.gov/node/12. PPMI evolved into the APPEL program in the 1990s.

[9]See http://pmperspectives.gsfc.nasa.gov/.

[10]See, for example, http://appel.nasa.gov/case_studies/case_study_near/near_case_study.html.

valuable lessons can be learned from case studies involving notable science missions such as Viking and NEAR, or from experimental piloted aviation programs, they cannot fully address what is needed for the multiple, parallel human spaceflight systems development programs required by the Vision for Space Exploration.

The various APPEL programs draw instructors from current and former senior NASA experts, academic professionals, and expert consultants. APPEL is in the process of developing a new, four-level, core curriculum for technical professionals in NASA by which an engineer or a manager can progress through a combination of multi-week courses and on-the-job experiences.[11] According to NASA officials, the program, which will stress an integrated approach to project management and systems engineering, has been slated for initiation in FY 2007.

APPEL also has developed a systems engineering "competency framework" that arrays lists of knowledge, skills, and behaviors that systems engineers should possess under 10 major competency areas—e.g., systems design, technical management, and project management and control—and defines four levels of proficiency that specify the degree of knowledge or performance that is expected of systems engineers for different levels of responsibility.[12] A matrix of competencies and proficiency levels is intended to be used to help determine specific training needs for individuals and organizations and to help guide planning for professional development for systems engineers. NASA has a similar matrix to facilitate the professional development of project managers.

The committee is concerned that at the same time NASA is seeking to acquire and develop the in-house technical capability that NASA's administrator, and the committee, believe is vital to successfully implementing the Vision for Space Exploration, the agency is simultaneously reducing its primary in-house training programs for project management and systems engineering. The committee believes that this trend must be reversed.

IMPROVING THE SUPPLY OF HIGHLY SKILLED PERSONNEL: THE ROLE OF THE EXPLORER PROGRAM, BALLOONS, AIRCRAFT, AND SOUNDING ROCKETS

The committee was informed by various experts that when it comes to developing systems engineering and project management skills, there is ultimately no substitute for hands-on training. Coursework is vital, but just as it is impossible to become skilled at baseball in a classroom, so also is it impossible to learn the necessary skills for managing and integrating complex spacecraft without actually working on them.

The importance of hands-on experience has been recognized often throughout NASA's history. In 1991, the National Academy of Public Administration completed a study of the distribution of NASA science and engineering work between NASA and contractors and described how that distribution might affect NASA's in-house capabilities.[13] Among the questions that the study considered were whether NASA had contracted out too much of its technical work to remain a "smart buyer," whether NASA's in-house technical capability had eroded over time, whether hands-on work was important to the development of a competent science and engineering workforce, and whether there were enough hands-on opportunities for NASA's workforce.

The NAPA report indicated that the balance of expertise had shifted away from NASA to contractors in a number of discipline specialty areas, including systems engineering, and consequently that NASA risked losing its ability to be a smart buyer and to properly manage technical work. The report cited evidence that fewer NASA scientists and engineers were working on hands-on R&D tasks and that there had been a shift to assigning more of the in-house staff to project management and operations support. This situation is remarkably similar to the situation that NASA officials have said they face today.

Although human and robotic systems are distinct, they do share many management and engineering processes as well as system technical characteristics. Given that the bulk of the development activities over the past 10 years have been in robotic spacecraft, NASA needs to leverage the robotic spacecraft workforce skill development opportunities to meet some of the human spaceflight program development skill needs. *The committee believes*

[11]The four levels cover (1) project management and systems engineering fundamentals, (2) management and systems engineering applications to small projects, (3) integration of advanced project management and systems engineering skills for large projects, and (4) and executive-level program management and assessment.

[12]See http://appel.nasa.gov/items/training/SE_Competency.pdf.

[13]National Academy of Public Administration (NAPA), *NASA Maintaining the Program Balance*, NAPA, Washington, D.C., January 1991.

that systems engineering methodology and technical skills acquired from complex robotic spacecraft development can serve as an important base for the transition to systems engineering of human spacecraft.

High-quality systems engineers and program or project managers cannot be trained entirely by universities, or by NASA's APPEL program; the skills required to become truly expert in those positions can only be acquired through on-the-job experience. However, NASA can take steps to help both university students and entry-level employees start along the road toward becoming a program manager or a systems engineer by increasing the number of development programs.

In addition to developing small spacecraft, NASA conducts several activities that are useful for providing hands-on experience to younger personnel. One of these activities is the agency's Explorer program. NASA's Explorer program consists of independent, robotic space missions designed to target a wide range of fields, including atmospheric, solar, and cosmic research. These missions are managed by the Explorer Program Office at Goddard Space Flight Center and are characterized by their moderate cost and shorter development time relative to the larger space observatories. Since inception of the program in 1958, 79 of 83 Explorer missions have been successful, and many have resulted in significant discoveries. However, the FY 2007 budget reduces the Explorer program by 20 percent, with no launches between 2009 and 2012.[14]

NASA has long supported several flight research programs that utilize specially equipped aircraft, high-altitude balloons, and suborbital sounding rockets to carry research instruments aloft for periods of time ranging from minutes to hours to days. The programs are notable for their relatively low costs compared with those for spaceflight missions, the relatively short turnaround time from payload design to flight (or reflight), and their relatively high risk tolerance compared with spaceflight missions. All of these attributes make suborbital projects especially valuable methods for giving junior-level scientists and engineers firsthand experience with mission systems design, development, testing, and operations (see Figure 4.1).

The current high-altitude balloon program provides about 20 research flights per year to altitudes above 30 km for flight durations of hours to days to as much as several weeks. The balloon program, which can carry research payloads of more than 1,000 kg, is utilized by researchers in atmospheric science, astronomy, high-energy astrophysics, and solar and space physics. According to NASA officials, the current balloon program involves about 40 institutions, 200 scientists and engineers, 25 graduate students, and 50 undergraduates. NASA balloon flight opportunities have decreased over the years, although individual flight durations have increased and the payloads have become more sophisticated, essentially "mini-satellites" in themselves, complete with solar panels, stabilization and communications systems, and instruments. However, the lower number of flights means fewer opportunities to fly payloads and gain experience (see Figure 4.2).[15]

The sounding rocket program provides opportunities to carry payloads in the range of several hundred kilograms to altitudes of hundreds of kilometers for flight durations of a few to more than 20 minutes (see Figure 4.3). Sounding rockets can carry stabilized platforms to facilitate the pointing of astronomical telescopes, and they also provide important opportunities for other types of research measurements in aeronomy, space plasma physics, and astrophysics. The program currently supports about 10 principal investigators per year at an annual flight rate of 10 to 20 flights per year.

The suborbital programs are particularly suitable means to provide less highly skilled engineers and scientists with direct hands-on experience with the full range of space mission tasks, including mission definition, design, development, flight operations, and data analysis. Thus these types of programs constitute an ideal medium for gaining skills that are important for systems engineers and project managers on larger spacecraft. The suitability of suborbital projects as training opportunities is enhanced by the fact that they can be conducted in relatively short periods of time (typically 1 to 3 years) and at relatively low cost and with a greater degree of tolerance for mission risk.

The number of suborbital flight opportunities has fallen dramatically over the past two decades. Figure 4.4 shows the annual number of sounding rocket flights from 1959 through 2005. The sounding rocket launch rate peaked at above 150 per year in the late 1960s, and it has subsequently fallen to less than 1/6 that launch rate now.

[14]See http://www.aaas.org/spp/rd/nasa07p.htm and http://explorers.gsfc.nasa.gov/schedule.html.
[15]See http://spacescience.nasa.gov/admin/divisions/sz/SEUS0402/Jones_Balloons.pdf.

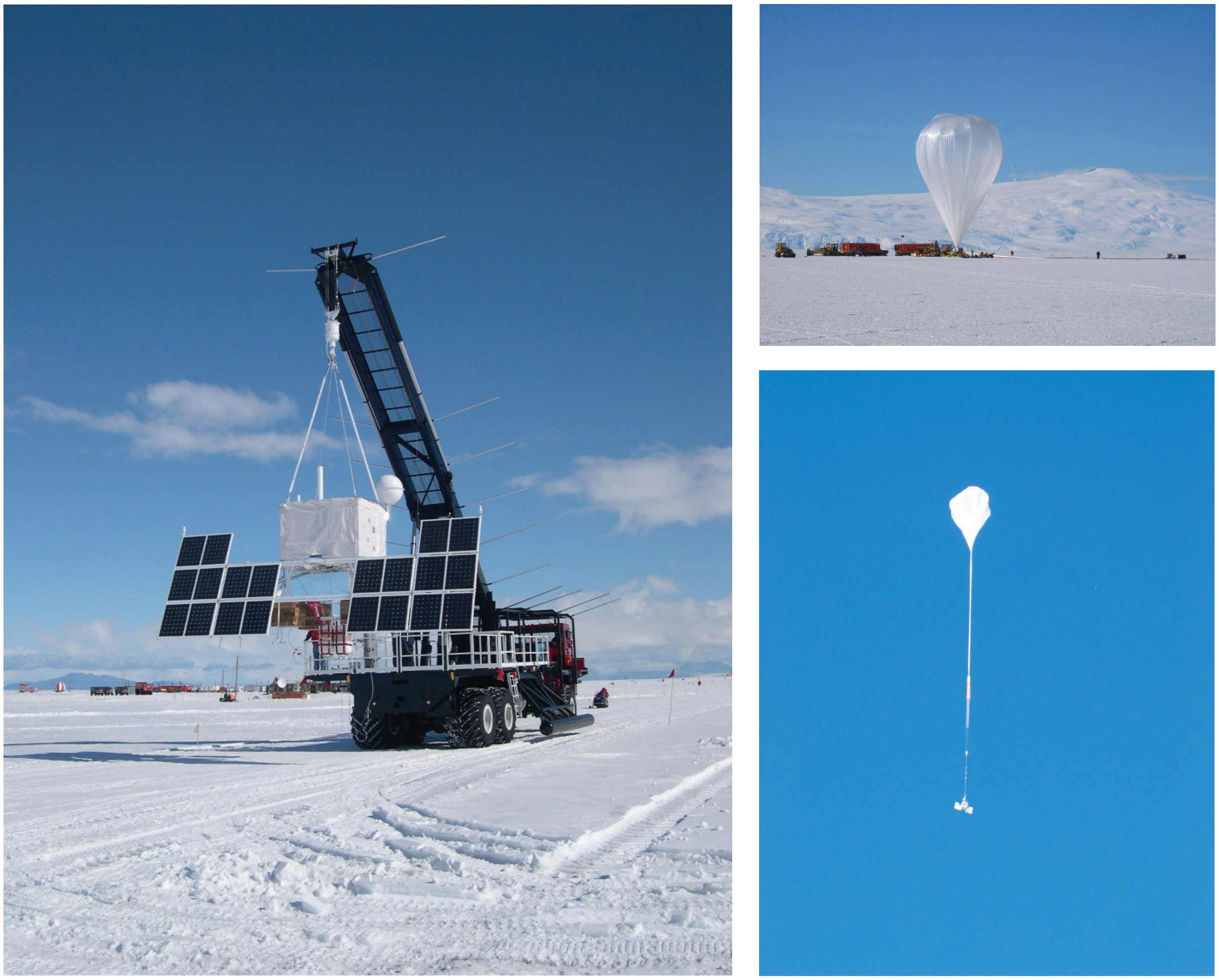

FIGURE 4.1 Preparation and launch of the CREAM experiment in Antarctica in December 2004. Such experiments are relatively low cost methods for conducting science and also provide valuable hands-on experience for space scientists and engineers. SOURCE: See http://cosmicray.umd.edu/cream. Illustrations courtesy of NASA and the University of Maryland.

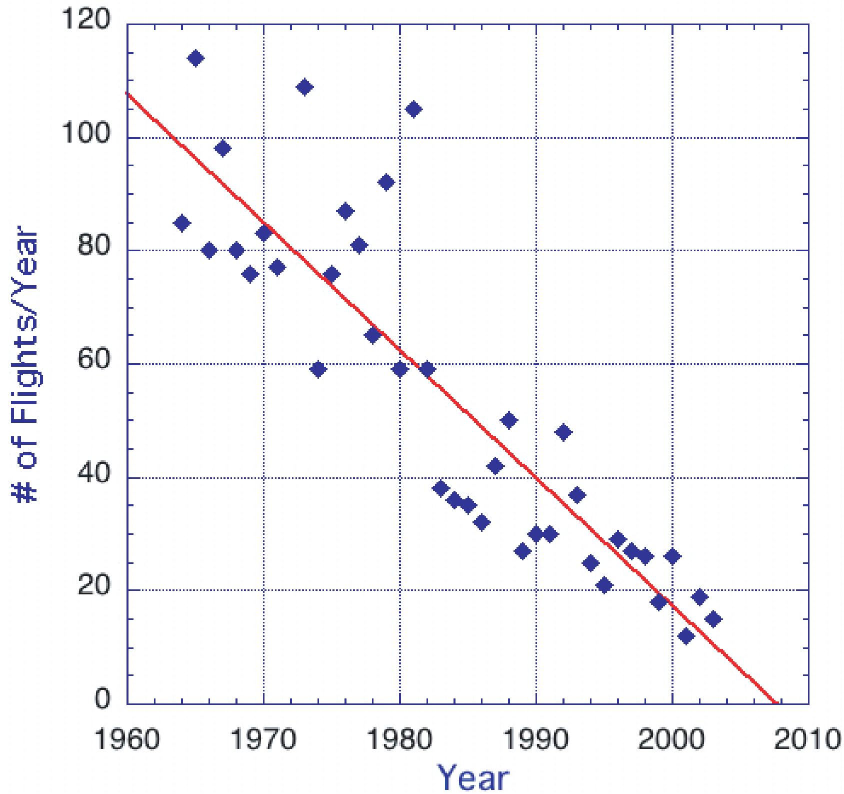

FIGURE 4.2 NASA's balloon launches by year. Balloon launches are a good proxy for hands-on flight programs that can provide critical experience to students and entry-level employees. SOURCE: Courtesy of NASA. See http://spacescience.nasa.gov/admin/divisions/sz/SEUS0402/Jones_Balloons.pdf.

(Similarly, balloon launches occurred at a rate of 70-90 per year in the 1970s but have fallen to fewer than 20 per year.) Several factors have contributed to the drop in the number of suborbital programs, including increased complexity and capability (and attendant costs) of vehicles and payloads, increased operating costs, and reductions in program budgets.

The committee believes that the Explorer program and its Earth Probe and Mars Scout counterparts, and balloon, aircraft, and sounding rocket flights should not be viewed by the agency simply as competed science projects, but also as internal and external training programs to develop expertise that is specifically needed by NASA. The agency should reinvigorate these programs. The committee believes that this can be accomplished with a relatively small amount of money that can be reallocated within the agency's current budget. Giving frequent flight opportunities to younger members in the NASA workforce—both in the civil service and in academia—will improve the skills that will be useful to the agency in future years.

Finding 4: There is a longstanding, widely recognized requirement for more highly skilled program/project managers and systems engineers who have acquired substantial experience in space systems development. Although the need exists across all of NASA and the aerospace industry, it seems particularly acute for human spaceflight systems because of the long periods between initiation of new programs (i.e., the Space Shuttle program in the 1970s and the Constellation program 30 years later). NASA training programs are addressing some of the agency's

FIGURE 4.3 (Left) Worker integrating the LaBelle payload for spin/balancing at the NASA Wallops Environmental Testing Facility. (Right) A Black Brant XI sounding rocket prior to launch. SOURCE: Courtesy of NASA.

requirements in this experience base, but the current requirement for a strong base of highly skilled program/project management and systems engineering personnel, and limited opportunities for junior specialists to gain hands-on space project experience, remain impediments to NASA's ability to successfully carry out VSE programs and projects.

Recommendation 4: Provide hands-on training opportunities for NASA workers.

The committee recommends that NASA place a high priority on recruiting, training, and retaining skilled program/project managers and systems engineers and that it provide the hands-on training and development opportunities for younger and junior personnel required to establish and maintain the necessary capabilities in these disciplines. Specific and immediate actions to be taken by NASA and other parts of the federal government include the following:

- **In establishing its strategy for meeting VSE systems engineering needs, NASA should determine the right balance between in-house and out-of-house work and contractor roles and responsibilities, including the use of support service contractors.**
- **NASA should continue and also expand its current employee training programs such as those being conducted by the Academy of Program/Project and Engineering Leadership (APPEL). To facilitate the development of key systems engineering and project management skills, NASA should increase the number of opportunities for entry-level employees to be involved in hands-on flight and end-to-end development programs. A variety of programs—including those involving balloons, sounding rockets, aircraft-based research, small satellites, and so on—can be used to give these employees critical experience relatively early in their careers and allow them to contribute as systems engineers and program managers more quickly.**

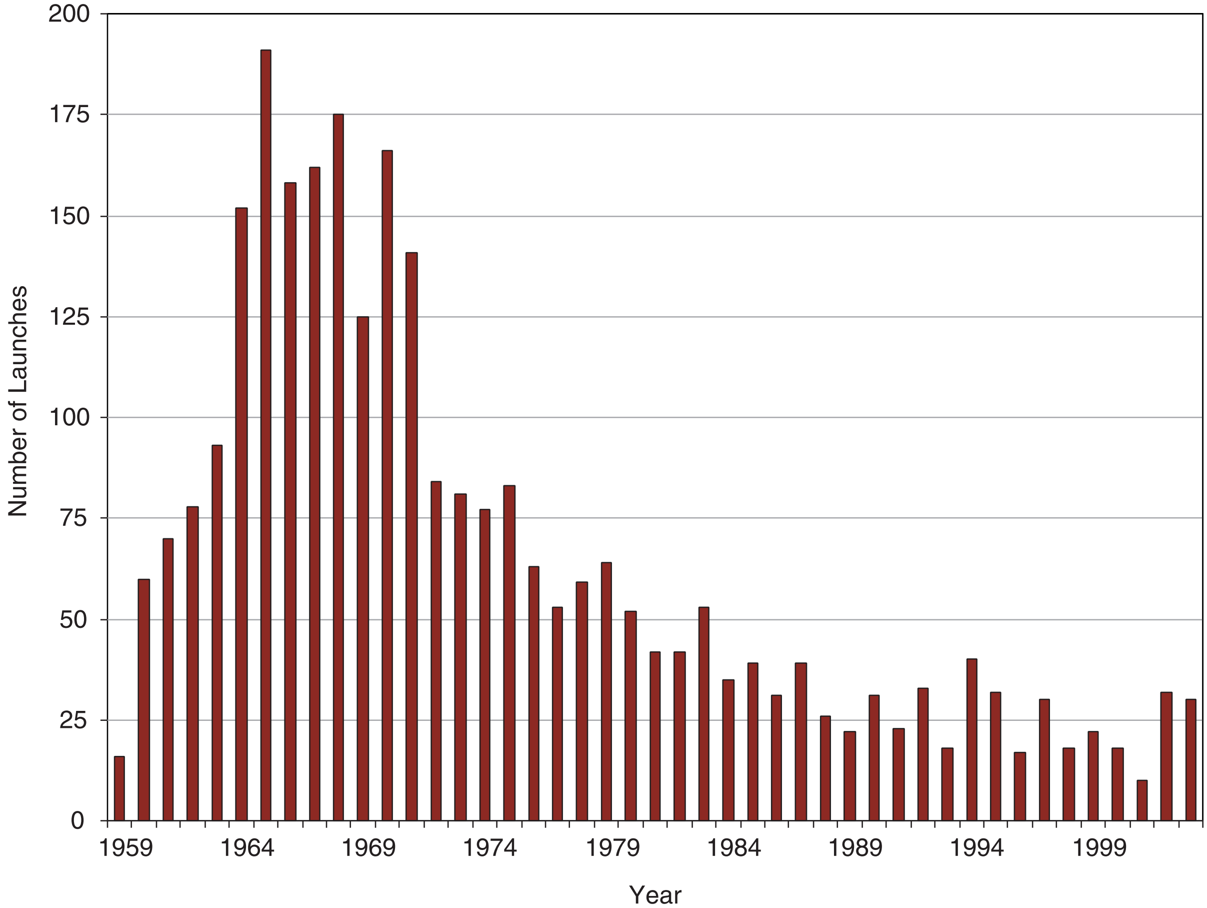

FIGURE 4.4 NASA's sounding rocket launches by year, from 1959 to 2005. Sounding rocket launches are a good proxy for hands-on flight programs that can provide critical experience to students and entry-level employees. SOURCE: Courtesy of David C. Black, Universities Space Research Association.

5

Roles of Academia and of Nontraditional Approaches

Most analysis of scientific data returned from NASA missions is performed by university faculty members working with students and more senior associates, all under NASA sponsorship. University faculty members and graduate students also do fundamental research in engineering sciences that leads to new technologies and new tools for space systems. Academics are often the ones to undertake the advanced development of scientific instruments and spacecraft systems technologies for future space missions.

The research component of the university endeavor is only part of the contribution from the academic sector, which also has a primary role in educating and supplying the workforce for NASA and industry. Thus the academic sector plays a large role in supplying new scientists, engineers, and support staff to conceive, develop, and conduct the research studies in NASA's science and technology programs.

At its January 2006 workshop and subsequent meetings, the committee heard from a number of faculty members and administrators from major university science and engineering schools regarding what factors contribute to either attracting or discouraging students from concentrations in space science and engineering. The most commonly cited factor, and possibly the factor that appears to have the greatest positive impact, relates to giving students opportunities for hands-on experience. The impact of hands-on experience can begin with undergraduate research opportunities, and such experience plays an important role as students decide on areas of graduate study concentration and career directions. Many university representatives noted the impact of giving students opportunities to participate in spaceflight missions, especially small university-led missions such as Explorers and suborbital flight research using aircraft, high-altitude balloons, and sounding rockets. In these programs students can get firsthand exposure to space project technology development, mission design and development, and science data analysis. They gain an end-to-end view of the development of a space project. Through these and other means, universities contribute to initial training and continued on-the-job training for space program professionals. As Chapter 4 notes, recent opportunities for the types of space projects most valuable for student training have been infrequent and, particularly in the case of the suborbital program, threatened with further reductions.

A second important factor in attracting students involves opportunities to participate in what they perceive as important endeavors. According to the committee's interviews and panel discussions, students need to believe that what they are doing will contribute to compelling (even transformational) scientific or engineering research and/or contribute to an important national goal such as space exploration. The goals need to be viewed as real and stable and as having the potential to contribute to important advances in a meritorious field. Other factors cited by the university representatives as being important in encouraging student interest included having positive personal interactions with faculty and receiving high-quality science instruction before entering college.

University representatives also cited a number of factors that they viewed as disincentives for students planning their career directions. Notable on that list were evidence of program instability or waning support (e.g., due to cuts in support for research on campus or reports of declining job opportunities), lack of opportunities for hands-on experiences in the area, and noncompetitive fellowship stipends. Other factors that tend to discourage student interest include negative interactions with faculty, poor science training in the primary education system, and perceptions about whether a field is "cool" or whether the academic workload is particularly difficult.

Although universities are training grounds for future NASA scientists and engineers, NASA's workforce competencies do not map directly to academic disciplines. Some competencies, such as software engineering and aerodynamics, match established university programs. The workforce pipeline can be monitored by watching the input and output of these programs, although the flow of new entrants to the workforce in these disciplines will be considerably affected by employment opportunities in industry or other sectors of the government. Other competencies are subfields within academic disciplines, or may appear in multidisciplinary university laboratories. Extravehicular activity (EVA) systems projects, for instance, may be located administratively in an aerospace engineering department, but the disciplines involved in developing EVA systems include mechanical and electrical engineering, robotics, human factors, and other specialties. Funding for research projects in these areas comes almost exclusively from NASA, and therefore NASA can affect, in both the positive and negative sense, the pipeline and the specific skills of graduates of these programs and the university workforce needed for continued basic research in the future. Still other competencies, such as project management, can be taught in theory in a formal graduate educational setting but require on-the-job experience to master.

EDUCATION OF POTENTIAL EMPLOYEES

Academia educates potential workforce employees at several levels. These are discussed below.

Entry-level "Fresh Outs"

More than 2,700 engineering programs in the country are accredited by the Accreditation Board for Engineering and Technology (ABET).[1] Accreditation standards are developed by ABET in collaboration with professional societies to set standards for what students should know and be able to do at the completion of their bachelor's degree. According to the standards, students must understand and be able to apply mathematics, science, and engineering; be able to identify, formulate, and solve engineering problems; work in teams; communicate effectively; understand the impact of engineering solutions in a global and societal context; and understand the professional and ethical responsibilities of an engineer.

Undergraduate students are being educated broadly within their disciplines, not trained for a specific segment of industry. However, NASA, by making project opportunities available at the university for undergraduate students, can encourage engineering departments to focus the design experiences of its students on problems of interest to NASA, and thereby to develop skills needed in its workforce pipeline. National design competitions, student rocket and balloon projects, individual scholarships and fellowships, and research grants that encourage participation of undergraduates are all possible strategies to attract student interest in NASA-related areas.

One particularly effective approach to recruiting undergraduates and accelerating their training is through cooperative education programs. In 2006 there were approximately 230 NASA co-op students who were drawn from about 130 colleges and universities. All NASA centers administer their own co-op student programs, with the largest number of students being at Johnson, Goddard, Langley, and Marshall. Half the centers support both undergraduates and graduate students in their programs. Until very recently, the co-op program was supported by center general and administrative (overhead) funds, but with the transition to full-cost management in the agency, some center co-op program administrators reported to the committee that program managers are showing reluctance to release scarce program funds to support co-op students.

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[1]ABET Inc. is the recognized U.S. accreditor of college and university programs in applied science, computing, engineering, and technology.

NASA might consider strategically focusing resources on a few selected undergraduate programs to establish pipelines of bachelor-level engineers who have the experience and skills needed to become new workforce entrants. Emphasis on hands-on opportunities in first- and second-year engineering will be important, both in recruiting students and in preparing them well. NASA will benefit in future years by increasing its support for activities at the college level that increase interest in space-related projects.

The First Professional Degree

According to *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*, the engineering bachelor's degree should be considered to be a "pre-engineering" or "engineer in training" degree.[2] The report recommends that the master of science (M.S.) degree be recognized as the first professional engineering degree and that institutions should encourage students to obtain M.S. and Ph.D. degrees. Many of the skills implied by the NASA "competencies" list (see Appendix C) are either not taught or not taught in depth in most undergraduate programs. NASA will need a workforce development program that provides opportunities for engineers to further their education formally in universities or with in-house programs or else institute policies of hiring entry-level engineers at the M.S. level.

While undergraduates are educated broadly within their disciplines, master's and Ph.D. education is generally more narrowly focused on specific subfields and skills. NASA and the aerospace industry can influence the content of graduate education programs in areas relevant to its mission by outsourcing basic research to universities. University faculty members are first-line recruiters for their graduate programs. *The extent to which the pipeline of M.S. and Ph.D. scientists and engineers is filled with students who are enthusiastic about the Vision for Space Exploration will be influenced by their involvement with NASA-related research during their graduate education.*

The pipeline of master's and Ph.D. engineers reflects the decisions of students and institutions, influenced by the availability of financial support and by the labor market for engineers with advanced degrees. Unlike practitioners of medicine and law, engineers can enter the workforce with only a B.S. degree. The difference in the expected lifetime earnings of a B.S.-level engineer versus an engineer with an advanced degree is not sufficient to entice students to incur massive debts in student loans required to obtain further education. NASA and the aerospace industry can affect the pipeline of M.S. and Ph.D. engineers by the decisions they make on funding for graduate student support at universities, and on the value they place on advanced-degree holders in the workforce. The committee believes that it would be of great value to NASA's workforce development to augment support available to technology graduate students through the Graduate Student Researchers Program (GSRP) (see Box 5.1).

NASA's Graduate Student Researchers Program targets individuals most likely to enter the NASA science and technology workforce. GSRP awards fellowships to students enrolled in master's or Ph.D. programs who propose research projects that are directly related to NASA problems. GSRP recipients work with faculty advisors at their home university as well as with NASA mentors at the various centers, acquiring skills that are important for the NASA workforce. Mentoring by NASA scientists and engineers and internships at NASA centers help to develop a cadre of potential master's and Ph.D.-level workers for the aerospace ecosystem, in general, and for NASA in particular. GSRP recipients also serve as a link between NASA and university faculty, a pool of potential "on-demand" experts who can be tapped as needed. Since the GSRP award, $30,000, is not adequate to fully support tuition and a stipend for a student, GSRP students may in some cases also be partially supported by NASA research grants. Both GSRP and university research grants are crucial in developing the future NASA workforce.

Some students pursue advanced degrees with the expectation of a significant financial return on their investment in one to several additional years of education. Others are motivated by the expectation of more varied and interesting opportunities throughout their careers. Institutions can encourage students to pursue graduate degrees but can succeed in doing so only if students' expectations are met after graduation. NASA and the aerospace industry can attract students to master's and Ph.D. programs by providing fellowships and funded research projects and,

[2] National Academy of Engineering, *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*, The National Academies Press, Washington, D.C., 2005.

BOX 5.1
NASA's Graduate Student Fellowship Programs

NASA's Office of Education lists four main goals for the agency: inspire, engage, educate, and employ. At the graduate student level NASA's education goals shift from inspiring and engaging prospective students to educating and employing them. This is meant to lead to a growth in the nation's science, technology, engineering, and mathematics workforce. Two programs—the Graduate Student Researchers Program (GSRP) and the Earth System Science (ESS) Graduate Student Fellowships—provide graduate students with funding, mentoring, and practical research experience. The Minority University Research and Education Program (MUREP) is designed to actively engage underrepresented and underserved minorities in NASA's activities, eventually leading to their employment in a science, technology, engineering, and mathematics discipline.

GSRP fellowships are offered to graduate students who intend to attain a master's or doctorate in a science, technology, engineering, or mathematics discipline. NASA lists 21 science fields, ranging from aerospace engineering to psychology, in which research can be pursued. In FY 1998 the program granted awards to 387 students, but the number of awards has gradually dropped, and in FY 2005 only 295 awards were granted. A GSRP slot is valued at $30,000 and awarded for 1 year; the award is renewable for up to 3 years. For comparison, graduate fellowship funding can reach $35,000 at NIH, $37,000 at EPA, $40,500 at NSF, $42,200 to $52,200 at DOE, and $55,000 at DOD. The committee notes that from a competitive standpoint, NASA is at a disadvantage compared to these other government agencies.

The $30,000 GSRP fellowship total includes a $21,000 student stipend, a student allowance of $5,000, and a $4,000 university allowance. None of these funds may be used to purchase equipment. The awardees have historically been 81 percent white and 66 percent male. Of the former participants reporting about their activities after the GSRP program, 11 percent were employed within NASA, and 40 percent were employed in aerospace-related jobs.

The ESS fellowship program has the same funding structure as the more general GSRP but focuses only on Earth system science topics, including climate variability and change, atmospheric composition, the carbon cycle and ecosystems, water and energy cycles, weather, and Earth's surface and interior. In FY 2006 177 slots were available in the ESS fellowship program, 21 more than in FY 1999 but 18 fewer than in FY 1994.

The MUREP includes multiple programs for various education levels. The Harriet G. Jenkins Fellowship Program (JPFP) provides funding for 3 years at GSRP levels to underrepresented graduate students, including women, minorities, and persons with disabilities, seeking a master's or a doctoral degree in a science, technology, engineering, or mathematics field. The fellowships also provide 6 weeks of research experience at a NASA center. The program supported 50 students in FY 2006, including 10 seeking a master's degree and 40 seeking a doctorate. Of the 107 students who participated in the JPFP during its first 5 years, 10 have already received a Ph.D. For FY 2005, 47 percent of participants studied engineering as a research discipline; 22 percent, astronomy or physics; 12 percent, biology; 11 percent, computer science; 5 percent, mathematics; and 4 percent, chemistry. Four former participants are employed at NASA, six are employed in the aerospace industry, and five are in higher education.

more importantly, ensuring that exciting career opportunities are available upon graduation. The VSE is particularly compelling to those who believe they can participate in it.

INNOVATIVE APPROACHES TO TRAINING POTENTIAL WORKERS

In this report so far, the committee has identified traditional approaches to developing a workforce. However, the committee also notes that the aerospace world is changing significantly and that, compared to even only a decade ago, there are many new and interesting approaches to expanding the available workforce.

FIGURE 5.1 Cubesats are small satellites that can be developed by students in a relatively short period of time, enabling them to obtain the experience necessary for future larger projects needed by NASA. SOURCE: (Left) Courtesy of Polysat, Calpoly.edu. (Right) Courtesy of Gary Swenson, University of Illinois at Urbana-Champaign.

Declining support for sounding rockets and high-altitude balloon programs is being matched by an overall trend toward declining support for activities focused on providing flight system and program management experience for students and entry-level employees.

The committee believes that training students to build satellites, gain hands-on experience with the unique demands of satellite and spacecraft systems, and acquire early knowledge of systems engineering techniques is an important resource for NASA. *NASA needs to play a role in training the potential workforce in the skills that are essential and/or unique to the work the agency conducts.* Sounding rocket and high altitude balloon programs can be an important way to get hands-on development and management experience for students and recent graduates; however, they are by no means the only way to accomplish this important training function. Indeed, by following the examples set by other agencies and other nations, NASA can have the best of both worlds—training the next generation of NASA leaders and innovators while also getting technologies and systems that will be useful in the short-term.

Many universities around the world have endeavored to take on nano-satellite projects, often called "cubesats"[3] (see Figure 5.1), that typically begin with the development of small spacecraft having no advanced sensors or large power demands. Once both the students and the university laboratories in which they work have become experienced in the field, they can then begin to develop impressive technologies at costs equal to or often dramatically lower than those for commercial products. A primary example of this phenomenon is Surrey Satellite Technologies,

[3]"Cubesats" are satellites that are 10 centimeters on a side, use commercial components, can carry one or two instruments, and can be made for $65,000 to $80,000 per satellite. See, for instance, www.space.com/businesstechnology/technology/050928_cubesats.html.

an enterprise started at the University of Surrey in the United Kingdom, which is currently a world leader in providing low-cost, robust, and proven satellite development and manufacturing. By providing mentorship and launch opportunities and thus encouraging the growth of similar programs in U.S. universities, NASA could enhance U.S. capacity in a field in which the United States has been surpassed by others, and could simultaneously educate and train a crop of students with the experience to be tremendous assets to the nation and specifically to NASA.

NASA also can emulate an inexpensive and effective method used successfully by the Department of Defense. The "Grand Challenge" prize, a $2 million cash prize offered by the Defense Advanced Research Projects Agency (DARPA), targeted university and amateur teams capable of developing autonomous vehicles (see Figures 5.2 and 5.3). The competition attracted entries from many of the country's leading universities, most of which partnered with leading industrial companies that provided cash to and mentored the competing students. In the end, DARPA's Grand Challenges program produced four winning teams and more than $170 million in investment over 2 years of competition. NASA could use its own Centennial Challenges prize program to achieve similar results, both financial and educational, by increasing the emphasis on this program beyond its current $9.7 million budget.

Previous prizes, ranging from the privately funded Ansari X PRIZE to the Department of Defense's Grand Challenges, have shown a consistent ability to motivate a wide variety of individuals, many of them entry-level, to explore new solutions to longstanding problems and to conduct entire missions on extremely low budgets.

NASA can also accomplish multiple goals by providing support to the emerging sector of new, small rocket companies often referred to as the "entrepreneurial space" or "alt-space" (or "new space") community. Although these companies often cannot compete with traditional aerospace companies in terms of entry-level salaries, they can promise new employees opportunities for innovation, responsibility, and a high degree of engagement. They can also offer superb value to NASA in some cases. For example, it has been reported that the SpaceShipOne suborbital manned spacecraft program (see Figure 5.4), accomplished by a company of ~100 employees, spent significantly less than the hundreds of millions of dollars estimated by standard cost models for the project if conducted by NASA or the traditional aerospace sector. By furthering its support of such entrepreneurial companies, NASA can simultaneously achieve value, increase the diversity of the marketplace, and encourage the education and training of entry-level employees.

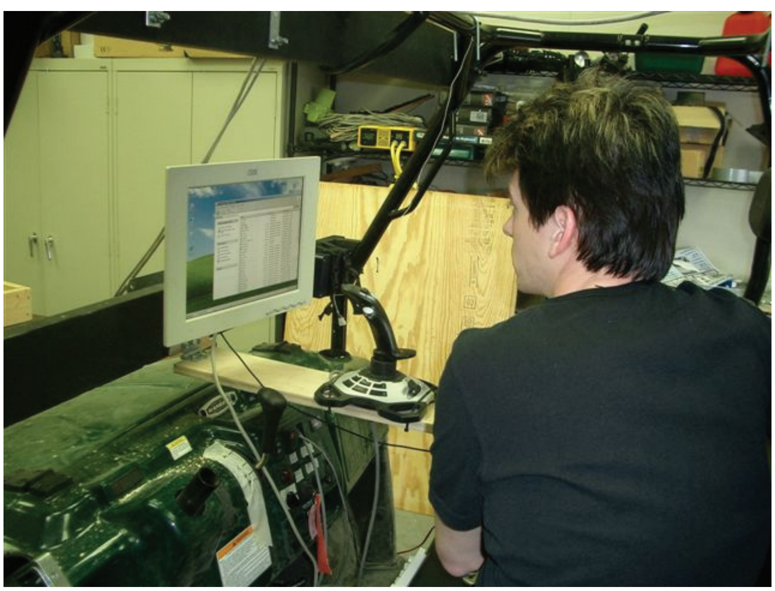

FIGURE 5.2 An Ohio State University student working on an entry in the DARPA Grand Challenge program. Such projects can tap new communities to work on NASA projects. SOURCE: Courtesy of Ohio State University.

FIGURE 5.3 The Defense Advanced Research Projects Agency (DARPA) Grand Challenge attracted 15 teams from all over the country to develop an autonomous robotic vehicle. Many of the teams had never worked on a Department of Defense project before and raised their own money to participate. SOURCE: Courtesy of DARPA.

A PARTNER IN SCIENCE AND ENGINEERING RESEARCH

Most scientific research in the disciplines relevant to space exploration technologies and systems, including astronomy and astrophysics, planetary (and lunar) science, solar and space physics, Earth sciences, life and biomedical sciences, and microgravity physical sciences, is carried out in university laboratories. Other institutions—NASA and other federal laboratories, not-for-profit organizations, and industry laboratories—certainly play significant roles, but the universities are the predominant performers in the United States.[4] The scientific activities involve all phases of the research process, including advanced technology development, definition of mission concepts and long-term planning, flight instrument development, flight mission science operations, and data analysis and interpretation. Based on NASA's current plans to support human exploration of space and at the same time continue a broad and balanced program of scientific research, the committee expects that U.S. universities will

[4]An important example of a critical scientific role played by scientists at NASA centers is the role of the project scientist. Ever since NASA's inception, project scientists have served as on-site representatives of the teams of scientists who participate in NASA science missions and who work on a day-to-day basis with project managers and engineers to assist in weighing trade-offs between often-competing technical, budgetary, and scientific demands or constraints of a mission. The in-house NASA scientists provide the expertise to help project managers make effective decisions about such trade-offs in a fashion that is quite similar to the way experienced project managers and engineers help make "smart buyer" decisions.

FIGURE 5.4 SpaceShipOne underneath its carrying aircraft. This project, inspired by the Ansari X PRIZE, was a low-cost effort relative to similar government programs. But it also offered a model of how to attract innovation and new workers to the field of aerospace development. SOURCE: Courtesy of Scaled Composites, LLC.

need to be able to sustain a high level of teaching and research expertise across all of the disciplines mentioned above and be able to support the full range of activities comprised by the research process.

The Vision for Space Exploration will require considerable investment in basic engineering sciences, particularly in fluid flow (not understood for microgravity environments), combustion, formal methods for software verification, protection from space radiation, and many other areas. Some of this work is needed in a short timeframe, and that work will probably be undertaken most effectively at NASA laboratories. But the VSE will require continued effort to develop systems that can function in the challenging environment of space. Research in these areas naturally falls into the category of investigation that is effectively carried out in university laboratories with the support of NASA programs.[5]

ACADEMIA AS A SOURCE OF EXPERT ADVICE FOR THE FEDERAL GOVERNMENT AND INDUSTRY

Since its establishment, NASA's support of academic research and teaching has been reciprocated by academia's contribution of expert advice in formulating mission plans, planning mission architecture, developing innovative instrumentation and spacecraft systems, and so on. Academic engineers offer a breadth of experience and lessons learned across many industries to bear on problems vital to the success of the VSE, and they can provide NASA independent guidance on what issues to examine and how to look at them. The availability of "on-demand" expertise through the academic sector increases NASA's capabilities in ways that would be extremely costly if NASA were to attempt to sustain in-house expertise in all conceivable specialties. The aerospace industry

[5]See, for instance, NRC, *Assessment of Balance in NASA's Science Programs*, The National Academies Press, Washington, D.C., 2006, pp. 24-28 and 31-32, for a discussion of the need for research in microgravity sciences.

also benefits from such advice. Continued support of the research expertise of the university sector can thus be viewed as of economic and technical value to NASA.

But the continued existence of university expertise in areas unique to NASA's missions will not be assured without investment of resources. University departments are often thought of as rigid, but they do change on multi-year time scales. In allocating "hunting licenses" for faculty renewal, university administrators typically ask about the intellectual importance of the field in which recruitment is proposed, and they consider prospects for future funding. They seek to appoint in areas at the cutting edge of knowledge and to assure themselves that the area will remain relevant over the multi-decade career of a typical faculty appointee. Long-term commitments of this sort are jeopardized if the area of research is not seen as one that will remain relevant and garner continued extramural support. Not only faculty selection is affected by changing NASA support for research: even in the selection of applicants for graduate education, universities seek assurance that a faculty advisor can make a 5- to 7-year commitment of financial support to a new Ph.D. student.

NASA needs to be particularly careful to nurture and sustain research areas of importance to the agency's mission and to recognize that frequently or abruptly changing goals and funding priorities may adversely affect the university partners on which NASA relies for many services.[6]

Finding 5: NASA relies on a highly trained technical workforce to achieve its goals and has long accepted a responsibility for supporting the training of those who are potential employees. In recent years, however, training for students has been less well supported by NASA. A robust and stable commitment to creating opportunities at the university level for experience in hands-on flight mission development, graduate research fellowships for science and engineering students, and research is essential for recruiting and developing the long-term supply of competent workers necessary to implement NASA's future programs.

- Faculty research not only is fundamental to student training but also leads to the development of new technology and tools for future applications in space. Programs supporting critical scientific and technological expertise are highly desirable.
- Hands-on experience for students is provided by suborbital programs, Explorer and other small spacecraft missions, and design competitions, all of which rely on continuing NASA support.
- The Graduate Student Researchers Program supports the education and training of prospective NASA employees and deserves augmented support.
- Undergraduate and graduate co-op student programs are particularly effective in giving students early hands-on experience and in exposing students and NASA to each other to help enable sound career choices and hiring decisions.

Recommendation 5: Support university programs and provide hands-on opportunities at the college level.

The committee recommends that NASA make workforce-related programs such as the Graduate Student Researchers Program and co-op programs a high priority within its education budget. NASA should also invest in the future workforce by partnering with universities to provide hands-on experiences for students and opportunities for fundamental scientific and engineering research specific to NASA's needs. These experiences should include significant numbers of opportunities to participate in all aspects of suborbital and Explorer-class flight programs and in research fellowships and co-op student assignments.

Finding 6: Although NASA's primary role is not education or outreach, improved support of the higher-education community and of young professionals is critical to maintaining a sufficiently talented workforce. Involvement in providing development and educational opportunities, especially hands-on flight and vehicle development opportunities, will pay future dividends not only by encouraging larger numbers of talented students to enter the field, but also by improving the abilities of incoming employees. Indeed, a failure to invest in today's students

[6] See, for instance, NRC, *Assessment of Balance in NASA's Science Programs*, The National Academies Press, Washington, D.C., 2006, pp. 14, 19, and 21, for a discussion of the impact of abrupt changes in programs and budgets.

and young professionals will ultimately lead to a crisis when that generation is expected to assume the mantle of leadership within the U.S. aerospace community.

Recommendation 6: Support involvement in suborbital programs and nontraditional approaches to developing skills.

The committee recommends that NASA increase its investment in proven programs such as sounding rocket launches, aircraft-based research, and high-altitude balloon campaigns, which provide ample opportunities for hands-on flight development experience at a relatively low cost of failure.

Rather than viewing sounding rockets, aircraft-based research, and balloon programs simply as low-cost, competed, scientific missions, NASA should also recognize as an equal factor in the criteria for their selection their ability to provide valuable hands-on experience for its younger workers and should investigate the possibility of funding such programs through its education budget.

In addition, NASA should take advantage of nontraditional institutions and approaches both to inspire and to train potential future employees. Investment in programs such as Centennial Challenge prizes and other innovative methods has the potential to pay benefits many times greater than their cost, by simultaneously increasing NASA's public visibility, training a new generation of workers, and pushing the technology envelope.

Appendixes

A

NASA Letter of Request

National Aeronautics and Space Administration
Headquarters
Washington, DC 20546-0001

September 30, 2005

Program Analysis and Evaluation

Dr. Lennard Fisk
Chair, Space Studies Board
National Research Council
500 Fifth Street NW
Washington, DC 20001

Dear Dr. Fisk:

The national Vision for Space Exploration calls for "a sustained and affordable human and robotic program to explore the solar system and beyond . . . starting with a human return to the Moon in preparation for human exploration of Mars and other destinations." The Vision projects a robust scientific program and the development and utilization of the space systems to enable substantial progress towards the lunar goals within ten years and the possibility of human Mars missions within 30 years. The implications for the future U.S. aerospace and scientific workforce to carry out such a sustained effort are every bit as urgent and challenging as the technological aspects.

The task of meeting NASA's workforce needs is daunting in view of the fact that the U.S. aerospace sector has been facing growing recruitment and retention problems for a number of years. In its 2004 report, the President's Commission on Implementation of the United States Space Exploration Policy stated that "there is perhaps no greater imperative for ensuring successful and sustainable space exploration by this nation . . . [than to] . . . aggressively educate and train a new generation of explorers."

Central to the workforce problems are the capabilities of the nation's research universities, which will have the responsibility both to encourage students to pursue careers in space and to provide the required training. This issue was also noted in the 2004 report: "At present, there are insufficient methods for students to acquire hands-on experience in the scientific and technical disciplines necessary for space commerce and exploration. Therefore, a new alliance between NASA and universities should be formed."

Consequently, there is a compelling need to carefully assess the current and future supply of a qualified U.S. aerospace workforce and to identify realistic, actionable solutions. At this time, I request that the Space Studies Board conduct a study in collaboration with the Aeronautics and Space Engineering Board to explore long-range science and technology workforce needs to achieve the Vision for Space Exploration, identify obstacles to filling those needs, and explore solutions for consideration by government, academia, and industry. Specifically, the study should undertake the following:

1. assess current and projected demographics of the U.S. aerospace engineering and space science workforce needed to accomplish the Vision;
2. identify factors that impact the demographics of the affected workforces;
3. assess NASA's list of the workforce skills that will be needed to implement the Vision for Space Exploration, both within the government and in industry;
4. identify the skills that will be needed to implement the Vision for Space Exploration within the academic community;
5. assess the current workforce against projected needs;
6. identify workforce gaps and analyze obstacles to responding to the workforce needs, in particular, analyze the proper role of academia and the obstacles for achieving this proper role; and
7. develop recommendations for specific actions by the federal government, industry, and academia to address those needs, including considerations such as organizational changes, recruiting and hiring practices, student programs and workforce training and improvement.

The study should utilize existing statistical data to assess the current and future shortfall of a qualified U.S. aerospace workforce and focus on the particular needs of NASA and the larger aerospace science and engineering community in the context of the long-term Vision for Space Exploration, recognizing legislative requirements regarding national security.

We would like to incorporate the results of the initial stage of the study into our strategic planning process during the current year; to do so, we need to receive your initial input by late in the first quarter of FY06. The report that presents findings and recommendations on the long-term workforce requirements and proposed solutions would be most useful if delivered by the last quarter of FY06.

Please feel free to contact Ms. Trish Pengra at (XXX) XXX-XXXX in my office for more information.

Sincerely,

Scott Pace
Associate Administrator for
Program Analysis and Evaluation

B

Statement of Task

The Space Studies Board and the Aeronautics and Space Engineering Board will organize a study to explore long-range science and technology workforce needs to achieve the nation's long-term space exploration vision, identify obstacles to filling those needs, and explore solutions for consideration by government, academia, and industry. The study will focus on the particular needs of NASA and the larger aerospace science and engineering community and will undertake the following tasks:

1. Assess current and projected demographics of the U.S. aerospace engineering and space science workforce needed to accomplish the exploration vision;
2. Identify factors that impact the demographics of the affected workforces;
3. Assess NASA's list of the workforce skills that will be needed to implement the Vision for Space Exploration, both within the government and in industry;
4. Identify the skills needed to implement NASA's Vision for Space Exploration within the academic community;
5. Assess the current workforce against projected needs;
6. Identify workforce gaps and analyze obstacles to responding to the workforce needs, and in particular, analyze the proper role of academia and the obstacles for achieving this proper role; and
7. Develop recommendations for specific actions by the federal government, industry, and academia to address those needs, including considerations such as organizational changes, recruiting and hiring practices, student programs, and existing workforce training and improvement.

C

NASA List of Competencies and Current Agency Workforce

TABLE C.1 Current Number of NASA Employees with Competency Specified

Competency	Count
Business Operations	1,439
Financial Operations	1,564
Institutional Operations and Support	660
Workforce Operations	298
Administrative Operations	1,243
Engineering and Science Support	976
Process Engineering	26
Systems Engineering	572
Test Engineering	187
Advanced Missions/Systems Concepts	151
Mission Analysis, Planning, and Design	129
Acoustics	51
Aerodynamics	113
Aeroelasticity	18
Aerothermodynamics	38
Air Traffic Systems	36
Flight Dynamics	16
Simulation/Flight Research Systems	74
Aerospace Medicine	26
Bioengineering	8
Crew Systems and Aviation Operations	64
Extravehicular Activity Systems	68
Environmental Control and Life Support Systems	42
Habitability and Environmental Factors	25
Human Factors Research and Engineering	59
Chemistry/Chemical Engineering	37
Pyrotechnics	10
Computer Systems and Engineering	141

continued

TABLE C.1 Continued

Competency	Count
Data Systems and Technology	20
Intelligent/Adaptive Systems	78
Network Systems and Technology	224
Neural Networks and Systems	3
Robotics	44
Software Engineering	297
Imaging Analysis	6
Avionics	77
Electro-Mechanical Systems	49
Electrical and Electronic Systems	201
Flight and Ground Data Systems	194
Control Systems, Guidance and Navigation	146
Micro-Electromechanical Systems	13
Metrology and Calibration Competency	0
Advanced In-Space Propulsion	25
Airbreathing Propulsion	30
Combustion Science	29
Hypergolic Systems	3
Nuclear Engineering/Propulsion	3
Propulsion Systems and Testing	120
Power Systems	127
Rocket Propulsion	109
Sensors and Data Acquisition—Aeronautics	48
Electron Device Technology	19
Electromagnetics	57
Laser Technology	20
Management	2,078
Microwave Systems	14
Optical Systems	74
Remote Sensing Technologies	71
Analytical and Computational Structural Methods	36
Materials Science and Engineering	209
Mechanics and Durability	30
Mechanical Systems	181
Non-destructive Evaluation Sciences	37
Structural Dynamics	64
Thermal Structures	15
Cryogenics Engineering	49
Fluid Physics Systems	60
Thermal Systems	108
Advanced Analysis and Design Method Development	48
Advanced Measurement, Diagnostics, and Instrumentation	71
Advanced Experimentation and Testing Technologies	125
Mathematical Modeling and Analysis	104
Nanoscience and Technology	13
Space Environments Science and Engineering	22
Advanced Technical Training Design	48
Mission Assurance	93
Mission Execution	490
Payload Integration	12

continued

TABLE C.1 Continued

Competency	Count
Weather Observation and Forecasting	6
Integrated Logistics Support	31
Program/Project Analysis	331
Technical Management	108
Quality Engineering and Assurance	230
Reliability and Maintainability Engineering and Assurance	37
Risk Management	15
Safety Engineering and Assurance	180
Software Assurance Engineering	19
Configuration Management	17
Program/Project Management	1,080
Astromaterials, Collections, Curation, and Analysis	5
Astrobiology	22
Astronomy and Astrophysics	106
Earth Atmosphere	123
Planetary Atmospheres	1
Planetary Science	67
Space Physics	74
Terrestrial and Planetary Environmental Science/Engineering	8
Biology and Biogeochemistry of Ecosystems	15
Earth Science Applications Research	37
Earth System Modeling	18
Geophysical/Geologic Science	10
Geospatial Science and Technologies	10
Hydrological Science	8
Oceanographic Science	12
Climate Change and Variability	4
Fundamental Physics	21
Icing Physics	9
Bioethics	1
Biomedical Research and Engineering	39
Biology	14

D

Biographical Sketches of Committee Members and Staff

DAVID C. BLACK, *Co-chair*, is the president and CEO of the Universities Space Research Association (USRA), a consortium of 97 different colleges and universities having graduate programs in space science or engineering. He is also adjunct professor of space physics and astronomy at Rice University. Between 1970 and 1975 Dr. Black served in various capacities at NASA's Ames Research Center, including chief of the Theoretical Studies Branch and deputy chief of the Space Science Division, and he was the first chair of the Ames Basic Research Council. Dr. Black was selected as the first chief scientist for the space station program at NASA Headquarters in 1985. He returned to NASA Ames in 1987 as the chief scientist for space research. He spent an academic year as a visiting professor at the University of London (1974-1975). Dr. Black is an internationally recognized researcher in theoretical astrophysics and planetary science, specializing in studies of star and planetary system formation. He has also done pioneering experimental research involving the isotopic composition of noble gases in meteorites, was the first to discover and correctly identify evidence for non-solar material in solar system matter, and was the first to show that the isotopic composition of solar flare noble gases differs from that of solar wind noble gases. He is a leader in the current effort to search for and study other planetary systems. He is past chair of the Solar System Exploration Subcommittee and the Origins Subcommittee of NASA's Space Science Advisory Committee. Dr. Black also served as a member of the NRC Planetary and Lunar Exploration Task Group (1984-1988) and the Working Group on Search for Extraterrestrial Intelligence (1979-1983).

DANIEL E. HASTINGS, *Co-chair*, is a professor of aeronautics and astronautics and engineering systems and dean for undergraduate education at the Massachusetts Institute of Technology (MIT). He was also the director of the MIT Engineering Systems Division and prior to that, the director of the MIT Technology and Policy Program. Dr. Hastings served as chief scientist of the U.S. Air Force from 1997 to 1999 and as chair of the Air Force Scientific Advisory Board from 2002 to 2005. He is currently a member of the National Science Board. In his role as chief scientist, he led several influential studies on where the Air Force should invest in space, global energy projection, and options for a science and technology workforce for the 21st century. Dr. Hastings' research at MIT has concentrated on issues related to spacecraft-environmental interactions, space propulsion, space systems engineering, and space policy. He has published papers and a book in the field of spacecraft-environment interactions and many papers on space propulsion and space systems design. Dr. Hastings has led several national studies on government investment in space technology. He has taught courses and seminars in plasma physics, rocket propulsion, advanced space power and propulsion systems, aerospace policy, and space systems engineering.

His recent research has concentrated on issues of space systems and space policy. Dr. Hastings is a fellow of the American Institute of Aeronautics and Astronautics and a member of the International Academy of Astronautics. He also served as a member of the National Academy of Engineering's Organizing Committee for Frontiers of Engineering (1996 and 1997). Dr. Hastings' NRC experience includes membership on the Government-University-Industry Research Roundtable (2000-2002), the Committee on Engineering Education (1999-2001), the Board on Engineering Education (1998-1999), the Committee on Advanced Space Technology (chair, 1997-1998), and the Aeronautics and Space Engineering Board (1996-1997).

BURT S. BARNOW is associate director for research and principal research scientist in the Institute for Policy Studies at Johns Hopkins University. Dr. Barnow's specialties include the evaluation of training programs and the operation of labor markets, and he has participated in recent relevant prior NRC studies on the nation's information technology workforce. He teaches the evaluation course in the institute's graduate public policy program and a course in labor economics for the Department of Economics. Before joining the Johns Hopkins' staff, Dr. Barnow was vice president of a consulting firm in Washington, D.C. He served 9 years in the Department of Labor, most recently as director of the Office of Research and Evaluation for the Employment and Training Administration. He is a member of the NRC Board on Higher Education and the Workforce, and he served as vice chair of the Committee on Workforce Needs in Information Technology (1999-2002).

JOHN W. DOUGLASS is president and CEO of the Aerospace Industries Association (AIA). Before joining AIA, Mr. Douglass served as assistant secretary of the U.S. Navy for research, development, and acquisition of defense systems for the U.S. Navy and Marine Corps. A nationally recognized expert in systems acquisition, Mr. Douglass has extensive acquisition experience in Congress, the Department of Defense (DOD), and the executive branch as a policy authority, contracting officer, engineering officer, test and evaluation officer, program control officer, and research director. Before being named a civilian Navy executive, Mr. Douglass was with the Senate Armed Services Committee where he was foreign policy and science and technology advisor to Senator Sam Nunn and served as lead minority staff member for defense conversion and technology reinvestment programs. Mr. Douglass completed 28 years of U.S. Air Force service and retired as a brigadier general in 1992. His numerous Air Force assignments included service as the deputy U.S. military representative to NATO as well as director of plans and policy and director of science and technology in the office of the secretary of the Air Force. He served on the Commission on the Future of the United States Aerospace Industry, which issued its final report in November 2002. Mr. Douglass served on the NRC Committee on the Future of the U.S. Aerospace Infrastructure and Aerospace Engineering Disciplines to Meet the Needs of the Air Force and the DOD (1999-2002).

RAY M. HAYNES is director of university alliances and development at Northrop Grumman Space Technology. He has more than 20 years of experience in the aerospace industry, and his positions ranged from design engineer and systems analyst to senior vice president of international operations. In 1984, he took a leave of absence from the aerospace industry to teach in academe. During that time, he was adjunct professor of operations management at Arizona State University and professor and co-director of the graduate engineering management program at Cal Poly, San Luis Obispo and received tenure there. During his academic career, Haynes published more than 100 articles/case studies on topics associated with engineering management and or/service operations optimization and leadership. He taught 27 different courses affecting more than 2,500 students in both undergraduate and graduate programs. Northrop Grumman currently has more than 100 "key" universities that provide technology, talent, processes, and enhanced customer relationships to the corporation. Haynes is active with several diversity initiatives, including being co-chair of the Native American Caucus at Northrop Grumman and a lifetime member of AISES and SACNAS, and he will co-chair the 2006 NAMEPA Conference in Phoenix.

MARGARET G. KIVELSON is Distinguished Professor of Space Physics in the Institute of Geophysics and Planetary Physics (acting director in 1999-2000) and the Department of Earth and Space Sciences (chair, 1984 to 1987) at the University of California, Los Angeles. She has served on the faculty since 1975. Her research interests are in the areas of solar-terrestrial physics and planetary science. She is known for work on the particles and magnetic fields in the surroundings of Earth and Jupiter and for investigations of properties of Jupiter's Galilean moons. She was the principal investigator for the magnetometer on the Galileo Orbiter that acquired data in Jupiter's magnetosphere for 8 years and is a co-investigator on various other investigations including the FGM (magnetometer) of the Cluster mission. Her honors include a Guggenheim Fellowship (1973-1974), the Radcliffe Graduate Society Medal (1983), the Harvard University 350th Anniversary Alumni Medal (1986), several NASA Group Achievement Awards, and memberships in the National Academy of Sciences, the American Academy of Arts and Sciences, and the American Philosophical Society. She is a fellow of the American Geophysical Union (AGU), the American Physical Society, the International Academy of Astronautics, and the American Association for the Advancement of Science. She was awarded the Alfven Medal of the European Geophysical Union and the Fleming Medal of the AGU in 2005. She has served on numerous advisory committees, including the NRC's Space Studies Board, and on scientific visiting committees at Harvard University, various campuses of the University of California, the University of Michigan, and the Jet Propulsion Laboratory. She has published more than 280 research papers and is co-editor of a widely used textbook on space physics. She lectures on her scientific interests to professional and public audiences and enjoys introducing K-12 students to the wonders of the solar system. She has been active in efforts to identify the barriers faced by women as students, faculty, and practitioners of the physical sciences and to improve the environment in which they function.

WILLIAM POMERANTZ serves as the director of space projects for the X PRIZE Foundation, where he currently manages the creation and operations of all of the foundation's new prizes in the field of aerospace. As an undergraduate, Mr. Pomerantz spent two summers at NASA's Goddard Spaceflight Center, where he served as a research associate in the NASA Academy. After graduating, he worked as a planetary geologist at Brown University prior to earning a master's degree at the International Space University. Mr. Pomerantz has also worked as an analyst at the Futron Corporation, an aerospace consultancy based in Bethesda, Maryland. He is the co-founder and editor of SpaceAlumni.com, an online news and social networking tool for young space professionals from around the world. Mr. Pomerantz is an officer of the ISU-USA Alumni association and a former officer of the Space Generation Foundation, the NASA Academy Alumni Association, and the Space Exploration Alliance.

JOSEPH H. ROTHENBERG is president and a member of the board of directors of Universal Space Network. From 1964 to 1981 he worked for Grumman Aerospace and was responsible for the development, test, orbital operations, and management for a number of NASA robotic spacecraft systems, including the Orbiting Astronomical Observatory Project and the Solar Maximum Mission. He joined NASA Goddard Spaceflight Center in 1983. In 1990 he was assigned as the Hubble Space Telescope Project Manager and led the highly successful first servicing mission that corrected the flawed optics. He became Goddard center director in 1995 and was responsible for managing space systems development and operations, and for execution of the scientific research program for the NASA Earth-orbiting science missions. In January 1998 he moved to NASA headquarters where he was named associate administrator for spaceflight and was in charge of NASA's human exploration and development of space. As associate administrator, Mr. Rothenberg was responsible for establishing policies and direction for the Space Shuttle and International Space Station programs, as well as for space communications and expendable launch services. Mr. Rothenberg served on the NRC Committee on Assessment of Options for Extending the Life of the Hubble Space Telescope (2004-2005) and is co-chair of the NRC Beyond Einstein Program Assessment Committee (2006-2007).

KATHRYN C. THORNTON is a professor in the Department of Science, Technology and Society, and in the Department of Mechanical and Aerospace Engineering, at the University of Virginia and is associate dean in the School of Engineering and Applied Science. Dr. Thornton served for 12 years as a NASA astronaut. She served on the NRC Aeronautics and Space Engineering Board (1998-2004) and the Committee for Technological Literacy (1999-2002).

Staff

DWAYNE A. DAY, study director, has a Ph.D. in political science from the George Washington University and has previously served as an investigator for the Columbia Accident Investigation Board. He 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 is 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 past and current NRC reports, including *Space Radiation Hazards and the Vision for Space Exploration* (2006), and for the Committee to Assess Solar System Exploration (2007).

JOSEPH K. ALEXANDER, senior staff officer, served previously as director of the Space Studies Board (1999-2005), deputy assistant administrator for science in the Environmental Protection Agency's Office of Research and Development (1994-1998), associate director of space sciences at NASA Goddard Spaceflight Center (1993-1994), and assistant associate administrator for space sciences and applications in the NASA Office of Space Science and Applications (1987-1993). Other positions have included deputy NASA chief scientist and senior policy analyst at the White House Office of Science and Technology Policy. Mr. Alexander's own research work has been in radio astronomy and space physics. He received B.S. and M.A. degrees in physics from the College of William and Mary. He served as the study director for the committee's interim report.

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

CELESTE NAYLOR joined the Space Studies Board in June 2002 as a senior project assistant. She has worked with the Committee on Assessment of Options to Extend the Life of the Hubble Space Telescope and also with the Committee on Microgravity Research and the Task Group on Research on the International Space Station. Ms. Naylor is a member of the Society of Government Meeting Professionals and has more than 7 years of experience in event management.

VICTORIA SWISHER joined the Space Studies Board in December 2006 as a research associate. She recently received a B.A. in astronomy from Swarthmore College. She has presented the results of her research at the 2005 and 2006 AAS meetings and at various Keck Northeast Astronomy Consortium (KNAC) undergraduate research conferences. Her most recent research focused on laboratory astrophysics and involved studying the x-rays of plasma, culminating in a senior thesis titled "Modeling UV and X-ray Spectra from the Swarthmore Spheromak Experiment."

MATTHEW BROUGHTON, Space Studies Board 2005 summer space policy intern, is a senior at Augsburg College pursing a bachelor of science in physics and a bachelor of arts in English. His undergraduate research has been in space physics, specifically the distribution of Pc 3-4 waves in the outer magnetosphere.

EMILY K. McNEIL, Space Studies Board 2006 winter space policy intern, graduated from Middlebury College with a B.A. in physics and astronomy. She has presented her undergraduate research at the American Astronomical Society meeting, the Posters on the Hill session on Capitol Hill, and two KNAC conferences. In February 2007 she began her doctoral work in astrophysics at the Research School of Astronomy and Astrophysics at Australian National University in Canberra.