Issues Affecting the Future of the U.S. Space Science and Engineering Workforce: Interim Report

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

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Committee on Meeting the Workforce Needs for the National Vision for Space Exploration
Space Studies Board
Aeronautics and Space Engineering Board
Division on Engineering and Physical Sciences
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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. The vision had 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 new spacecraft for transporting humans into space, developing a lunar lander spacecraft, and building new launch vehicles for both spacecraft.

On September 30, 2005, Scott Pace, National Aeronautics and Space Administration (NASA) Associate Administrator for Program Assessment and Evaluation, sent a letter to Lennard Fisk, chair of the National Research Council (NRC) Space Studies Board (SSB), requesting that the SSB and the Aeronautics and Space Engineering Board (ASEB) help assess the current and future supply of qualified U.S. aerospace professionals and identify realistic, actionable solutions to meeting any identified needs (see Appendix A). In late 2005, the NRC Committee on Meeting the Workforce Needs for the National Vision for Space Exploration was formed under the auspices of the SSB and ASEB to respond to the NASA request. The committee (Appendix F) comprises 9 members from a diverse range of backgrounds and includes experts from both the science and the engineering communities, as well as members who reflect the traditional U.S. science and technology triangle of government, academia, and industry. The committee also includes members from the emerging entrepreneurial community, as well as experts from outside the space community.

The committee was tasked with conducting a study to explore long-range science and technology workforce needs to achieve the nation's space exploration vision, identify obstacles to filling those needs, and put forward solutions for consideration by government, academia, and industry. The study's focus is the particular needs of NASA and the larger aerospace science and engineering community. The full statement of task for the study is in Appendix B.

On January 23-25, 2006, the committee held a 2-day workshop to identify the important factors affecting NASA's future workforce and its capacity to implement the new vision. The specific goal of the workshop was to identify and shape the issues to be explored by the committee in preparing its final report and to identify the available data on NASA's workforce. The workshop involved approximately three dozen participants from government, academia, and industry. The full workshop agenda and participant list are in Appendix C. At a second meeting on February 22, 2006, the committee gathered additional information regarding the results of NASA's analysis of current and future workforce competencies, and it also had discussions with representatives from the Bureau of Labor Statistics and aerospace industry. The agenda for that meeting is in Appendix D.

This document, which responds to NASA's request for an interim report on the results of the initial stage of the study, presents the committee's summary of highlights of the workshop and provides initial, but incomplete, findings with respect to the first three items in the study charge, namely to:

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; and
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.

This interim report also presents initial recommendations that stem from the committee's conclusions to date. The committee's full report will be completed in early 2007.

Acknowledgment of Reviewers

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

Robert D. Braun, Georgia Institute of Technology,
Gerald J. Chodil, Ball Aerospace Corporation (retired),
Raymond S. Colladay, Lockheed Martin Astronautics (retired),
Lennard A. Fisk, University of Michigan,
Ron Hira, Rochester Institute of Technology,
Martin H. Israel, Washington University, St. Louis, and
Ronald L. Oaxaca, University of Arizona.

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

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Summary

This report of the Committee on Meeting the Workforce Needs for the National Vision for Space Exploration responds to NASA's request for an interim report on a study to explore long-range space science and engineering workforce needs to achieve the nation's space exploration vision, identify obstacles to filling those needs, and recommend solutions for consideration by government, academia, and industry. The report presents a summary of highlights of a January 2006 workshop and a February 2006 committee meeting on the future of the U.S. aerospace space science and engineering workforce, and it provides some preliminary findings with respect to (1) current and projected characteristics of the workforce, (2) factors that impact the demographics of the affected workforces, and (3) NASA's list of the workforce skills that will be needed to implement the nation's vision for space exploration, both within the government and in industry. The report also presents initial recommendations that stem from these findings and initial conclusions.

There have been numerous recent studies and assessments of aspects of the future viability of the U.S. science and engineering workforce, including both broad macro-level examinations of the technical workforce across all disciplines and sectors and more focused assessments of the outlook in specific fields, such as aerospace science and engineering. These studies have considered such factors as the increasing fraction of the current workforce that soon will become retirement-eligible and the impact of science and mathematics education in the United States in the face of increasing globalization of industry. Studies that have looked in detail at the workforce for the U.S. space program have expressed concerns about the impact of shrinkage of the workforce during the aerospace industry's consolidation in the 1990s, competition for students from other technical fields that may be perceived as more exciting or having more growth potential, and a possible shortage of graduates who are eligible to receive clearances to work in areas covered by the International Traffic in Arms Regulations (ITAR).

NASA's interests in the workforce question were heightened by President George W. Bush's January 2004 announcement of a new civil space policy that would refocus NASA's broad range of research and engineering projects toward the human and robotic exploration of the Moon, Mars, and eventually other solar system bodies. This new vision for space exploration specified a phase-out of the space shuttle by 2010 and development of a new human launch vehicle to support human space missions as early as 2014, and a human return to the Moon between 2015 and 2020. NASA is using those new goals to reshape the agency's workforce in order to better align the mix of skills with the needs for future missions, and to ensure that NASA will have the necessary skills to achieve the new vision. Consequently, NASA sees a need to identify those skills that will no longer be needed, take steps to retrain and reshape the workforce, and be able to provide specific skills that will be needed in the future.

NASA's workforce issues can be thought of in terms of three timescales:[1]

1. *Immediate near-term*—the workforce problems that NASA is facing at the present moment, particularly the agency's concerns about its internal skill mix and (approximately 900) underutilized civil service staff at selected centers. This time frame is too short to be within the scope of the committee's

[1] These dates are from NASA's internal SEITT study and were provided to NASA's mission directorates in a survey of future workforce needs. See: "SEITT's Identification of Workforce Competencies to Support the Vision for Space Exploration," presentation to the Space Studies Board / Aeronautics and Space Engineering Board Committee on Meeting the Workforce Needs for the National Vision for Space Exploration, Jerry W. Simpson, February 22, 2006.

charge, and the committee did not issue findings and recommendations concerning it. However, the committee notes that it will shape perceptions among current and potential employees about stability and opportunities in the civilian space program.

2. *Mid-term, present to 2012*—corresponds with the retirement of the space shuttle in 2010, completion of International Space Station construction, the period for development of a crew exploration vehicle and crew launch vehicle, and the early development of the lunar exploration hardware.

3. *Long-term, post-2012*—the period during which NASA will be conducting full-scale development of the human lunar exploration systems.

The committee understands that NASA has concentrated heavily to date on the immediate near-term problems. However, except for the results of some modeling of age and retirement eligibility demographics, the committee received little information about NASA analyses or planning for the mid- or long-term workforce *skill mix* demand or supply. The one exception with respect to skill mix was NASA's observation about an agency-wide need for systems engineers and project managers. This concern is widely shared by senior managers in the Department of Defense (DOD) and industry, as well. During the workshop NASA did not discuss plans or options for training activities to address the agency's mid- and long-term needs in any detail. The committee did not see any information about whether or how the agency might be coordinating with other agencies (e.g., DOD) that are facing similar workforce concerns. DOD has created several programs to develop systems engineers, but there was no indication that NASA is working with DOD on these programs.[2]

The committee's initial examination of relevant demographic data about aerospace workforce supply and demand led to the following conclusions. First, although there are currently some problems in meeting demand, particularly for specific skills, the situation for employers such as the DOD and the large aerospace companies is not now a major problem. Data on employment demand are difficult to obtain, particularly broken down by relevant skill areas, and those data and projections that exist are often ambiguous as one looks beyond the near-term future. Second, many longer-term projections do forecast a gap between supply and demand that is larger than exists today. However, the size and scope of the gap are not clear. Third, the problems with meeting future demand in the DOD are influenced by the need to employ U.S. citizens and permanent residents who can obtain security clearances. NASA's workforce pool will be constrained in a similar fashion as the DOD's because NASA must hire people who can work in areas controlled by ITAR. Fourth, people with strong technical backgrounds can often acquire the specialized knowledge to go into different (but related) fields. Consequently, recruitment need not be too tightly targeted to the momentarily required specializations. Finally, NASA's mono-generational employee age distribution (i.e., having a peak at only a single age; see Chapter 2) is different from the distribution seen for the DOD and industry, both of which were described at the workshop as being either bimodal or more nearly like the distribution of the U.S. workforce as a whole. However, so far NASA has only begun to examine skill distribution and is becoming aware that it has an age distribution problem, but the committee saw no indication that the agency has begun to act on this concern.

NASA is not currently experiencing a supply problem in terms of overall available personnel. But the agency is experiencing a more complex and subtle problem that will grow over time. Like other government agencies and aerospace contractors, NASA is experiencing difficulty in finding experienced personnel in certain areas, such as systems engineers and project managers. NASA's workforce also has a skewed age distribution arising from hiring policies first implemented in the 1990s. The agency did not experience a hiring freeze during that time, but it adopted policies whereby it filled specific positions but did not hire younger people and "grow" them into positions. As a result, the agency's mean age has

[2] In January 2004 President Bush signed the NASA Flexibility Act of 2004 (P.L. 108-201). The act authorized NASA to increase recruitment, relocation, and retention bonuses, and it streamlined the hiring process for recent graduates. It also expanded pay flexibility and authorized science and technology scholarships that can pay for a student's undergraduate or graduate school education in return for a commitment by the student to work for NASA for a prescribed period of time following graduation.

continued to rise over time, and it lacks younger employees with necessary skills. As the agency embarks on new human and robotic exploration programs, problems in fulfilling demand will likely increase because the agency has not been developing the necessary employees from within.

The January workshop illuminated the following factors that will influence the demographics of the future aerospace science and engineering (S&E) workforce.

- *Perception*—Potential employees need to be convinced that the vision for space exploration is an exciting effort, that it is sustainable, that they can play an important role, that they can receive training or experiences that will help in future jobs, and that their potential co-workers and managers are committed.
- *Stability*—Will the overall effort be sufficiently large to maintain constant staffing, incorporate reachable and significant milestones that can serve as starting points for both employees and employers, and be based on a vision viewed as having a sustained duration long enough on which to build a career?
- *Availability*—Will key vacancies be open for competition, thereby creating an environment that encourages and facilitates the movement of NASA employees into industry for developmental work experience assignments, the movement of industry employees into NASA where they can mentor NASA employees, and the subsequent return of these employees to their original institutions?
- *Recruitment*—Can NASA and industry properly identify required skills in advance, whether the workforce has reliable and effective feeder programs, and how much attention is paid to expanding the diversity of the workforce and recruiting from underrepresented populations?
- *Retention and engagement*—The ability to pay competitive salaries, maintain employees' sense of usefulness, prepare employees for future contributions in addition to current contributions, listen to inputs from employees, provide mentors and training, and facilitate the transfer of know-how from senior to younger employees.
- *International involvement*—Although ITAR constraints may lead to a higher demand for U.S. citizens and permanent residents than might be the case in other employment sectors, international participation in space exploration will still have a significant impact on supplying members of the workforce.

During the January workshop participants raised a number of other notable points:

- NASA's attention to workforce issues seems primarily internally focused, but a more outward looking approach is desirable that accepts that industry and academia are integral parts of the workforce.
- A solution to NASA's near-term problems will not come via training students, because that is too long a process. Instead, exchanges with industry and academia are more promising for the near term.
- There will be a need for more organizational transparency to promote the flow of workers between NASA, industry, and academia.
- Workforce pull will be more important than push; jobs will have to be made attractive to meet workforce demand.

Based on the workshop discussions and additional information that the committee gathered at its second meeting, the committee has the following preliminary findings:

1. NASA has made a reasonable start on assessing its near- and long-term skill needs, and the committee shares the view expressed by NASA representatives that there is still much more work to be done. However, NASA's work has focused on initial assessment of current workforce demographics and estimates of future needs. NASA has not yet translated that analysis into a strategy and action plan. NASA's lack of work to date limited the committee's ability to assess exactly what needs to be done.

2. NASA needs a strategic workforce plan that deals with the next 5 years and that lays the foundation for a longer-term process. This will be a new and difficult process for NASA, but it will nevertheless be vital for the agency's success in implementing the space exploration vision.

3. The committee has not seen compelling evidence for a looming, broadly based shortage in the supply of aerospace S&E workforce employees to meet NASA's needs.

4. To address those skill areas where there are concerns (both for the near term and the longer term), NASA needs to pay particular attention to identifying and expanding ways to promote exchanges of personnel between NASA and the private sector (industry, academia, and non-government organizations).

5. The degree to which the agency chooses to perform work in-house versus by a contractor will play a major role in the number of personnel that the agency will require.

6. The committee concludes that the ability to recruit and strategically retain the needed workforce will depend fundamentally on the long-term stability of the vision for space exploration and a sustainable national consensus on NASA's mission.

The committee makes the following recommendations:

1. **NASA should develop a workforce strategy for ensuring that it is able to target, attract, train, and retain the skilled personnel necessary to implement the space exploration vision and conduct its other missions in the next 5 to 15 years.** The agency's priority to date has been to focus on short-term issues such as addressing the problem of uncovered capacity (i.e., workers for whom the agency has no current work).[3] However, NASA soon might be facing problems of expanding needs or uncovered capacity in other areas and at other centers. Therefore, it is important to develop policies and procedures to anticipate these problems before they occur.

2. **NASA should adopt innovative methods of attracting and retaining its required personnel and should obtain the necessary flexibility in hiring and reduction-in-force procedures, as well as transfers and training, to enable it to acquire the people it needs. NASA should work closely with the DOD to initiate training programs similar to those that the DOD has initiated, or otherwise participate actively in the DOD programs.**

3. **NASA should expand and enhance agency-wide training and mentorship programs, including opportunities for developing hands-on experience, for its most vital required skill sets, such as systems engineering.** This effort should include coordination with DOD training programs and more use of exchange programs with industry and academia.

Finally, the committee wishes to stress that this is an interim report. The committee still has to complete its examination of the role that universities play in supplying, training, and supplementing NASA's workforce. Part of this assessment will be to consider the role that universities can play in providing hands-on space mission training of the workforce, including the value of carrying out small space missions at universities. The committee also plans to review the final version of NASA's Systems Engineering and Institutional Transition Team (SEITT) report. The committee will evaluate the skills that the study identifies as necessary to implement the vision for space exploration, assess the current

[3] "Uncovered capacity" is NASA's term for a serious problem with workers for whom the agency has no current work. When NASA cuts programs or reduces budgets, it is left with civil service personnel who may no longer have work to perform. Unlike industry, NASA cannot simply lay off these unneeded workers, but must conform to a complex set of civil service rules. Normally the agency will have some uncovered capacity in its workforce, but in 2005 and into 2006 this number was identified as constituting a significant percentage of its total workforce. During that time NASA was also forbidden by law from conducting a reduction in force, or RIF, to reduce its workforce. As a result, the agency exercised alternative methods to reduce this excess workforce and cut the excess capacity in half by January 2006. The cumulative effects of paying for unnecessary employees can damage the agency in a number of ways, including diversion of tight program funding and the use of poorly qualified employees for work that might otherwise be performed by contractors.

workforce against projected needs, and identify gaps and obstacles to responding to NASA's projected needs. In its final report, the committee expects to develop recommendations for specific actions by the federal government, industry, and academia, including organizational changes, recruiting and hiring practices, student programs, and workforce training and improvement to enable NASA to accomplish the goals of the vision.

1
Introduction and Background

On September 19, 2005, NASA Administrator Michael Griffin held a press conference at which he unveiled the agency's plan for the human lunar exploration program. 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."[1] Griffin was not the first NASA administrator to warn of this problem. NASA has been facing the impending retirement of a significant percentage of its workforce for many years now. For instance, in December 1999, NASA Administrator Daniel Goldin stated that the retirement of NASA's workforce was an "overwhelming issue" that would overshadow the agency's outlook for the next 5 to 10 years.[2]

This problem may not be as pressing as it would seem, because the agency has traditionally benefited from having employees who stay at the agency beyond their retirement eligibility date. But NASA is not alone in being concerned about its workforce. Over the past several years there have been numerous studies and investigations into the composition of the science and technology personnel base to meet larger U.S. needs such as national security and international economic competitiveness. In fact, this subject has received frequent attention ever since the launch of Sputnik in October 1957. At numerous times over the past five decades, high-level study groups, including special presidential commissions, have warned of impending problems and recommended various solutions. Despite their frequent emphasis on the dire consequences of inaction, their warnings have not always been heeded, but when they have been, the typical response by the federal government has been to increase funding for education at multiple levels with the goal of producing more scientists and engineers.

This issue has reemerged on the national stage in the context of U.S. technological and economic competitiveness, primarily with respect to the emerging economies of China and India. President George W. Bush recently unveiled the American Competitiveness Initiative, a 10-year, $136 billion plan to double research spending on the physical sciences, enact a permanent research and development tax credit, and train more scientists and engineers. This initiative appears to have been influenced, in part, by a 2005 National Academies' report, *Rising Above the Gathering Storm.*[3] That report made four basic recommendations focusing on K-12 education, research, higher education, and economic policy.

In general, the current discussion of U.S. high-technology workforce needs can be divided into two broad categories, higher-level "macro" studies of the overall subject, such as the *Gathering Storm* report, and more focused, industry or area-specific studies. For instance, high-technology agencies such as the Department of Defense (DOD) have also sponsored recent studies focused on specific parts of the U.S. industrial base, such as aircraft carrier production and weapons system acquisition. These area-specific studies are of greater applicability to NASA.

For example, in 2001, Booz Allen Hamilton conducted a study for the National Reconnaissance Office on the military space industrial base that echoed the statements of NASA administrators by

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[1] See <www.nasa.gov/pdf/133896main_ESAS_rollout_press.pdf>, p. 35.

[2] See <www.space.com/news/nasa_workforce_991215.html>.

[3] National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*, Executive Summary [prepublication], The National Academies Press, Washington, D.C., 2005. Available at <darwin.nap.edu/execsumm_pdf/11463.pdf>.

warning that the average age of the space workforce was increasing.[4] More recently, the military services have experienced serious problems in the acquisition of several DOD space systems that have been blamed on management problems caused by poorly trained or unqualified personnel, funding instability, and overly ambitious requirements. 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, such as those conducted by the RAND Corporation concerning the United Kingdom's shipbuilding and submarine manufacturing base, have identified the dangers of allowing specific areas of expertise and workers' skill sets to atrophy and disappear—reconstituting these capabilities later may be very expensive.

The recommendations produced by the macro and area-specific studies may not always be compatible. The macro studies are generally focused on enlarging the overall base, whereas the area-specific studies sometimes recommend solutions that favor one part of the technical base over another, requiring favoring one field or government agency over another, or, at the very least, prioritizing responses within an agency. As several surveys of the overall S&E workforce have demonstrated, fields that were once highly attractive to technically-trained college students, such as aerospace engineering, have now been supplanted by other fields, such as software development and genetic engineering. 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 more attractive alternatives in other fields and when a large infusion of new funding into the space program is not likely.

THE VISION FOR SPACE EXPLORATION

In January 2004, almost 1 year following the loss of the Space Shuttle Columbia and her crew, President Bush announced a new civil space policy that would refocus NASA's broad range of research and engineering projects toward the human and robotic exploration of the Moon, Mars, and eventually other solar system bodies. This new vision for space exploration specified human lunar missions as early as 2015, but no later than 2020. Although neither the President nor NASA explicitly endorsed a specific time line for a human Mars landing, the vision does embrace human missions to Mars as an eventual goal after the return to the Moon.

As a consequence of this redirected U.S. space policy, the NASA leadership has restructured the agency, which now includes the Exploration Systems Mission Directorate and Science Mission Directorate, with overlapping responsibilities for implementing the vision, as well as 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. NASA Administrator Griffin has stated that he has no plans to further restructure NASA.

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, and the NRC workforce committee was briefed on the results at the January 23-24, 2006, workshop.[5]

The ESAS report outlined a space exploration approach requiring a new crew exploration vehicle for ferrying humans into space, a lunar surface access module for landing astronauts on the Moon, and

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

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

two new rocket vehicles for carrying these vehicles into space. The rocket vehicles would be the crew launch vehicle and the heavy lift launch vehicle. Both would rely substantially on space shuttle components. Although the specifics of the lunar landing architecture are subject to change, development of these new spacecraft and launch vehicles clearly represents a technical development challenge and will require significant systems integration expertise. 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.

NASA is also pursuing the development of two precursor robotic lunar spacecraft and continuing its robotic exploration of Mars. These efforts will also require competent personnel to manage them and interpret their data.

NASA has other major aspects of its overall space program that are not exclusively part of the vision for space exploration but that may impact or interact with it in various ways. These include the agency's broad space science program, encompassing not only planetary science but also Earth sciences, heliophysics,[6] and astrophysics. The NASA administrator has noted 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 the past NASA has also supported a broadly based research program in the physical and biological sciences in microgravity, but recently that program has been scaled back and focused more narrowly on (primarily biomedical) areas that NASA views as being in direct support of nearer-term aspects of the vision for space exploration. Similarly, NASA fostered and expanded the study of astrobiology in the 1990s, creating a base of expertise for the agency to draw on for its future science missions. But that program is also being scaled back.

Finally, the agency still maintains an aeronautics research program which is currently undergoing substantial refocusing and redirection. The aeronautics program is beyond the scope of the committee's charge.

In addition to these recent developments, NASA Administrator Griffin has announced his intention to conduct more technical development work inside NASA, as opposed to relying on the private sector. Griffin has expressed concern that NASA's internal technical skills have atrophied over time and need to be restored.

THE NASA SCIENCE AND ENGINEERING ENTERPRISE

The modern U.S. scientific and technical enterprise was forged during World War II and based on a triangular relationship between government institutions, industry, and academia. NASA has relied on this relationship since its creation in 1958. For instance, most scientific analysis of data returned from NASA missions is performed by university researchers under NASA sponsorship, and most spacecraft are built by industry. Very few of these activities are actually conducted by NASA employees.

Each of these institutions has different roles and challenges associated with their respective workforces. 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 the largest 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. 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 and industry and universities have played critical roles in providing on-the-job training for space program professionals.

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[6] Heliophysics involves the study of the Sun, the interplanetary medium from the Sun to the interface between the heliosphere and the interstellar medium, and interactions of the Sun and interplanetary medium with solar system objects. It was formerly called Sun-Earth Connections by NASA.

THE NASA WORKFORCE ENVIRONMENT

The committee defines in its broadest sense the workforce needed to accomplish the vision for space exploration. That is, to succeed in accomplishing the goals of the vision 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. Consequently, the committee will need to examine all these sectors to address its charge. This national civil space workforce is highly geographically dispersed. NASA's own field centers are spread across the country. When one considers the contributions from industry and universities, the locations of workers who will contribute to the effort will be found in every state in the Union. In recognition of this, NASA has created the Systems Engineering and Institutional Transition Team (SEITT), which is charged with making recommendations in four areas—human capital and workforce, organization and management, support requirements and contracts, and infrastructure to fulfill the agency's requirements for the space shuttle, the International Space Station, and the exploration systems architecture.

Some current statistics help to explain the state of the agency with regard to its civil service engineering workforce. According to the Office of Personnel Management, from 2001 to 2005 the number of engineers employed at NASA declined from 11,051 to 10,766. NASA hired only 411 new engineers in 2005, or approximately 3.8 percent. Of these only 6 were transfers from other agencies, indicating a lack of mobility within the government. During the same period, 749 engineers left the agency. At the time this report was written, the NASA jobs Web site showed openings for approximately 160 positions for an agency with nearly 11,000 engineers—a relatively small number of openings. NASA wages have been increasing and appear to be competitive. For example, from 2001 to 2005 engineering salaries rose from a mean of $80,195 to $97,998. These statistics demonstrate that the agency is currently contracting slightly, is eliminating engineering positions, and is not hiring many new people. Combined with other data that demonstrate a steadily increasing mean age of the workforce, it is clear that NASA is not simply suffering a supply problem, but is also experiencing changes in its workforce demographics as a result of agency policies and restrictions on its ability to hire and fire personnel.[7]

Although the committee was impressed and intrigued by what it heard at the workshop and at its second meeting, the committee's overall conclusion was that substantial, high-fidelity demographic data on NASA's existing workforce and future needs is still necessary but does not yet exist. Without it, the committee cannot draw meaningful conclusions about the agency's ability to effectively meet the goals of the vision for space exploration. The committee awaits the completion of the SEITT study, currently scheduled for April 2006, to determine if sufficient data is available.

At a time when the engineering architecture and budget for the vision have drawn intense scrutiny, and when large space development projects have run into schedule and financial trouble, the quality and skill mix of the agency's workforce will play a major role in NASA's ability to implement the vision, and they therefore deserve intense scrutiny as well.

[7] See <www.fedscope.opm.gov/>.

2
NASA's Exploration Plans and Workforce Implications

In the opening session of the January 23-24, 2006, workshop, NASA's Associate Administrator for Program Assessment and Evaluation, Scott Pace, addressed NASA's workforce from the perspective of the vision for space exploration. He noted that the vision, which aims to accomplish "a sustained and affordable human and robotic program to explore the solar system and beyond," provides a goal on which to focus in reshaping the agency's workforce so as to provide the desired long-term sustainability. That reshaping will be required to better align the mix of skills with the needs for future missions and ensure that NASA will have the necessary skills to achieve the vision. He indicated that while most of the skills that are now available via the agency's workforce will continue to be important to implement future exploration programs, there is a need to identify those skills that will no longer be needed, take steps to retrain and reshape the workforce, and build a capability to provide specific skills that will be needed in the future. Pace noted that, in contrast to NASA's space science program, the agency has not done as good a job in replenishing its talent pool in the human spaceflight program.

Pace briefly described the formation of NASA's Systems Engineering and Institutional Transition Team (SEITT), which was charged with assessing the institutional implications of the agency's new plans for the space shuttle, the International Space Station, and the exploration systems architecture. Created in June 2005 and consisting of approximately 25 people, the SEITT was asked to make recommendations in four areas—human capital and workforce, organization and management, support requirements and contracts, and infrastructure.

In assessing the makeup of NASA's workforce, the SEITT learned that the current age distribution of the civil service workforce is mono-generational, meaning that the distribution shows a *single* sharp peak in the age range from 40 to 44. (See Figure 2.1.) At higher ages the distribution for NASA's workforce falls off at the same rate as the age distribution for the total U.S. workforce.

On the other hand, there is a striking difference between the age distributions for NASA's workforce and for the total U.S. workforce at ages below 40. The U.S. workforce also peaks in the 40s, and it falls relatively slowly for younger ages, whereas the NASA workforce distribution drops rather precipitously below age 40 and has a marked gap at younger ages—it is more concentrated around a single age group than is the U.S. aerospace workforce as a whole. NASA analysts have referred to this disproportionately small number of younger workers as NASA's "Gen-X gap." The substantially smaller number of NASA workers in the 25- to 29-year age band will be the workforce that will have to implement the exploration vision over the next 15 years, raising the question of whether NASA will have sufficient numbers of highly trained personnel to accomplish its goals.

Finally, Pace provided a glimpse of the results of NASA's assessment of future skill needs. He indicated that areas for which there would be a growing need for civil service skills included systems engineering; mission analysis, planning, and design; aerospace medicine; software engineering; and control systems, guidance, and navigation. By contrast, he cited process engineering as an example of a skill that NASA would need less in the future.

Pace acknowledged that as individual programs and areas of research are restructured or eliminated, it is possible that the agency could lose skills and capabilities that it might eventually need to reacquire, e.g., in space life sciences. The committee agrees that, as other areas of high-technology research, development, and engineering have demonstrated, replenishing lost skills may be costly.

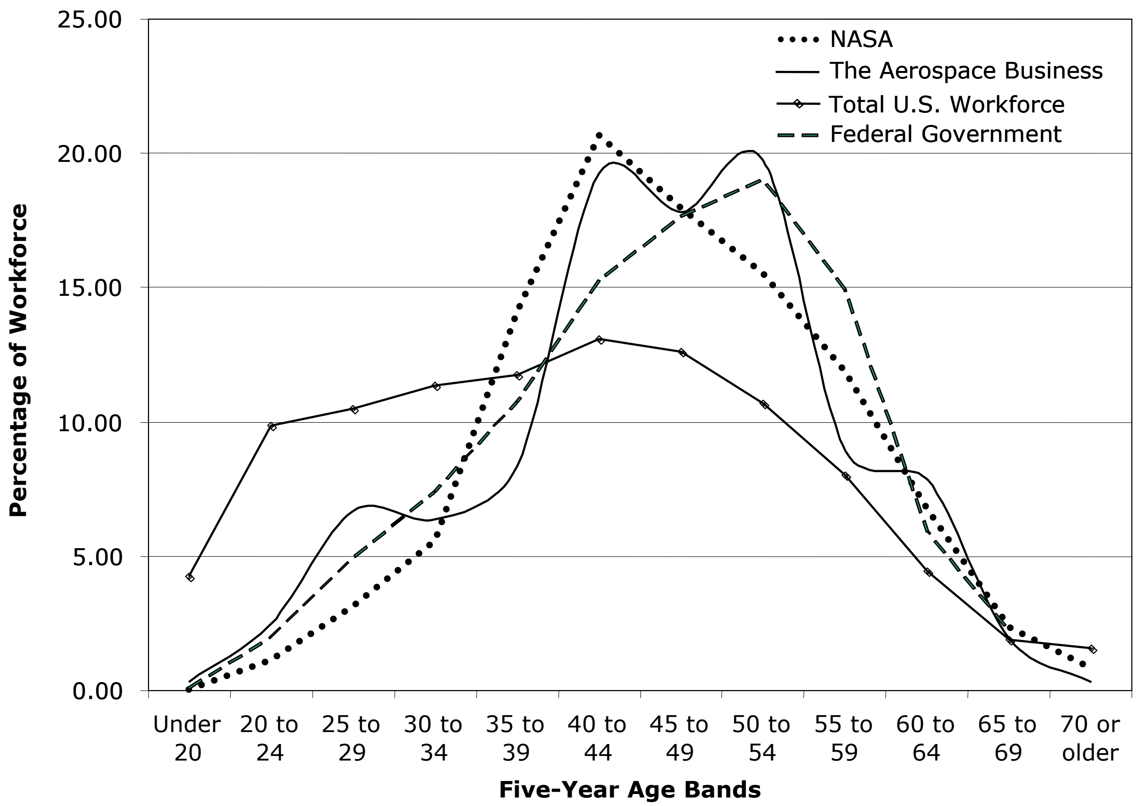

FIGURE 2.1 The age distribution of NASA's current workforce compared to the totals for the aerospace sector, the federal government, and the U.S. workforce. SOURCE: Garth Henning and Richard Leshner, NASA, presentation to the Committee on Meeting the Workforce Needs for the National Vision for Space Exploration, February 22, 2005.

Pace also noted that there are a number of factors that will complicate NASA's workforce challenges, such as uncertainties about the future pace and scope of some program areas (e.g., nuclear systems), program volatility (e.g., the near-term reductions versus longer-term needs in life sciences), outside competition for workers, NASA's need to hire U.S. citizens, workers' ability to rotate between NASA and industry (i.e., with NASA employees working at an industry site and industry employees working at NASA sites), and NASA's immediate needs for workers who already have significant experience rather than more junior people who require training.

The committee notes that one difficulty in understanding and characterizing NASA's potential workforce problems is that the agency's job definitions do not correspond with the standard occupational classifications produced by the Bureau of Labor Statistics. The problem is not that the agencies and BLS use different classifications (although that problem existed in the past), but that the BLS occupational classifications lack sufficient detail to be useful to NASA. This is a common problem as well for other fields, such as information technology, where an occupation such as "computer programmer" does not indicate which type of programming languages a person is knowledgeable about. The challenge for the committee—or anyone attempting to assess NASA's workforce problems—is that it is difficult to compare the agency's demand for workers with the available supply.

Michael Hecker, Acting Director of Constellation Systems in NASA's Exploration Systems Mission Directorate, summarized NASA's exploration and systems architecture plans for accomplishing the exploration vision (see Chapter 1). He described NASA's plans for organizational roles and relationships to accomplish the missions in the exploration roadmap and, by implication, provided some insight into where classes of workforce skills will be needed. NASA plans to have a streamlined headquarters directorate management office that will be responsible for strategic and policy direction, cross-program integration, program guidance, and reviews and oversight. Program management responsibility will be distributed across three NASA centers (Ames Research Center, Johnson Space Center, and Langley Research Center), which will be responsible for cross-project integration, assessment and evaluation, balancing requirements, and program insight. Management of specific projects will be assigned to individual NASA centers, where project offices will be responsible for project implementation via either in-house teams or out-of-house contracts. Hecker indicated that NASA's general approach will be to assign front-end technology development to in-house NASA center teams, while major systems development work would be done by industry. Systems operations responsibilities may be shared by centers and industry.

Kenneth Ledbetter, Chief Engineer of NASA's Science Mission Directorate, provided an overview of NASA's space and Earth science program and highlighted currently operating and planned missions and future technology development needs. He noted that the program has a total of 54 missions that are currently in operation and another 54 missions that are in formulation or in development. This set of robotic missions spans the scientific disciplines of astrophysics, heliophysics, planetary science, and Earth science. Ledbetter explained that program elements include a range of major, moderate size, and small principal-investigator-class space missions as well as a portfolio of basic and applied research grant projects in scientific data analysis, theory, suborbital flight investigations, and technology development.

Ledbetter described the concept of a "science ecosystem" that has three components with the following key roles:

- NASA centers
  —Program and project management
  —Development of at least one flight mission at all times to maintain key skills
  —Mission-enabling technology development
  —Scientific research in support of missions
- Industry
  —Contractor base for centers
  —Capacity to serve as systems integrator, prime contractor, or subsystem contractor
  —Engineering and fabrication capabilities
- Universities
  —Training and research
  —Home of many mission principal investigators
  —Instrument technology development

Finally, Ledbetter addressed several current challenges that will have an impact on the future space program workforce. First, reduced budgets and cost performance problems with small principal-investigator-class missions are leading to a reduced flight frequency for these missions and, consequently, reduced opportunities to expose graduate students in science and engineering to end-to-end experience with the design and development of spaceflight missions. Second, budget pressures on small suborbital flight programs (aircraft, high-altitude balloons, and sounding rockets) and on funding for instrument technology development are also reducing the number of opportunities in these programs, with attendant deleterious impacts on opportunities for young scientists and engineers. Third, Ledbetter referred to the "graying" of the scientific workforce, in which 60 percent of NASA's Ph.D. scientists are over the age of 50. The latter situation could lead to a significant shrinkage in NASA's civil service science cadre in the coming years.

Toni Dawsey, NASA's Assistant Administrator for Human Capital Management and Chief Human Capital Officer, discussed NASA's workforce and workforce strategy. She noted that almost 60 percent of the agency's 18,400 civil service staff are scientists and engineers. Within the science and engineering (S&E) cadre 90 percent are engineers and 10 percent are scientists. Consistent with the mono-generational distribution described by Pace, the average age of NASA scientists and engineers is 45.8; 24 percent are under 40, 67 percent are between 40 and 59, and 9 percent are 60 or older. NASA finds that 12 percent of its engineers and 21 percent of its scientists are now eligible to retire, and the agency projects that in 2011 28 percent of the engineers and 45 percent of the scientists will be eligible to retire. Off-setting the prospects for mass retirements 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.[1]

Dawsey cited a variety of recruitment, retention, and relocation incentives that are available to the agency, including co-op, student loan repayment, special appointment, and bonus programs. She noted, however, that the major challenge is the need to reshape the workforce to respond to the requirements for implementing the exploration vision. This challenge includes a short-term need to balance work amongst the NASA centers and deal with uncovered capacity, support the transition from the space shuttle to the crew exploration vehicle, and reshape the aeronautics program. There is also a long-term challenge to provide for a viable workforce to support exploration programs. NASA is dealing with the short-term problem through job fairs, job transition assistance activities, buy-outs, and early outs. Dawsey reported that slightly more than 1,000 uncovered employees have been accommodated through such efforts but that about 900 other positions that are considered to be "unfunded capacity" still need to be addressed.

The SEITT activity has been addressing the longer-term issues so as to identify the skills needed for space exploration and other parts of NASA's mission. The study 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 would dramatically alter the types of skills needed by NASA, as well as their numbers and distribution. The SEITT developed a spreadsheet listing 110 "workforce competencies" currently in the NASA workforce and defined in the agency's Competency Management System. It then worked through the headquarters mission directorate offices to characterize the relevance of each competency and chose a time designator (present to 2011, 2012 to 2018, beyond 2018) for when the competency might be needed, or how it would be trending. The team sought to identify lists of skill areas that will be needed by each NASA mission directorate for the three time periods. Its analysis has focused on what skills will be needed but not on the size of the workforce in competency areas. A key assumption for the analysis was that there would be 10 "healthy" NASA field centers during this entire period.

Among the SEITT findings noted by Dawsey were the following:

- All skills represented in the current NASA workforce are required to some degree;
- No new skills were identified that do not currently exist within the current NASA workforce;
- Forty percent of all skills were identified as critical to multiple NASA mission directorates;
- Fifty percent were identified as being critical to a single mission directorate;
- All mission directorates recognized the criticality of two skills—systems engineering and program/project management;
- Eighty percent of skills are directly related to human exploration work;
- Reductions in the shuttle/space station contractor workforce are projected to affect a far greater number of skills than will reductions in the civil service workforce; and
- The definition of work content and required positions in the NASA mission directorates is still not yet mature enough to plan the numbers of employees needed with a particular skill or their center locations beyond a very short horizon.

[1] 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.

Dawsey also noted that the agency is currently prohibited from laying off employees (a so-called reduction in force, or RIF) until spring 2007. Dawsey concluded by noting that NASA's work on a workforce strategy will be used in a report to Congress in April 2006.

Jerry W. Simpson, from NASA's Program Analysis and Evaluation Office, provided additional information to the committee on February 22. The SEITT identified 88 competencies inside NASA most directly related to human exploration. Simpson noted that 28 percent of the 110 competencies on NASA's master list of competencies were estimated to have increased demand during the near term (2006 to 2011), 16 percent were estimated to have a decreasing near-term demand, and 16 of the skill areas were identified as not being primary for any of the mission directorates. (See Appendix E for NASA's list of competencies and the number of employees currently possessing them.) But the SEITT's overall conclusion was that too many unknowns exist to develop firm strategies for workforce hiring. Among the remaining uncertainties, Simpson cited expected but undefined changes in aeronautics programs, uncertain schedules for the Shuttle program, the effects of a 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 interest.

At the committee's February meeting, NASA representatives also noted that the problem with near-term "uncovered capacity" was unlikely to be a one-time (current) event or a situation confined to only a few centers, but it would probably occur at nearly all centers at some point in the future as programs and projects transitioned. They also noted that NASA's initial modeling of longer-term workforce dynamics suggests that one of the primary factors affecting management of the NASA workforce is the degree to which NASA conducts R&D work internally versus having it done by a contractor—the so-called "make/buy" factor. NASA's civil service workforce is a small fraction of the total combined workforce engaged in NASA projects. Small changes in how this total workload is assigned to civil servants or to contractors can create large changes in the demand for these civil servants.

GENERAL CONCLUSIONS

In summary, based on the presentations noted above and on ensuing discussions during the workshop, NASA's workforce issues can be thought of in terms of three timescales:

- *Immediate near-term*—the workforce problems that NASA is facing at the present moment, particularly the agency's concerns about its internal skill mix and (approximately 900) underutilized civil service staff at selected centers;
- *Mid-term, present to 2012*—corresponds with the retirement of the space shuttle in 2010 and completion of International Space Station construction, and the period for development of the crew exploration vehicle and the early development of the lunar exploration hardware; and
- *Long-term, post-2012*—the period during which NASA will be conducting full-scale development of the lunar exploration hardware.

Addressing the immediate near-term issue is outside the committee's charge and beyond its ability to offer timely advice.

The committee understands that NASA has concentrated heavily on the immediate near-term problem. However, except for the results of some modeling of age and retirement eligibility demographics, the committee received little or no information about the extent to which NASA has conducted analyses or planning for mid- or long-term workforce *skill mix* demand or supply. The one exception with respect to skill mix was NASA's observation about an agency-wide need for systems engineers and project managers. During the workshop NASA did not present information about plans or options for training activities to address mid- and long-term agency needs. The committee did not see any information about whether or how the agency might be coordinating with other agencies (e.g., the

Department of Defense (DOD)) that are facing similar workforce concerns. DOD has created several programs to develop systems engineers. There was no indication that NASA is working with DOD on these programs.

The committee also notes that one of the primary factors affecting management of the NASA workforce is the degree to which NASA conducts R&D work internally versus using a contractor. Administrator Griffin has stated his intention to perform more work in-house at NASA. This decision could have substantial impacts on the number and type of employees the agency will need.

3
Science and Engineering Workforce Demographics

There have been many efforts by various organizations to examine demographic aspects of the U.S. aerospace workforce and the science and engineering workforce more broadly. These include statistical surveys of undergraduate and graduate enrollment and degree award trends and assessments of past and projected future employment numbers as a function of area of expertise, employment sector, and student or employee nationality. This chapter summarizes highlights of several of these studies that were discussed at the January 23-24, 2006, workshop.

NATIONAL SCIENCE FOUNDATION STUDIES ON ENROLLMENT AND GRADUATION TRENDS

The National Science Foundation (NSF) has a long history of tracking data on science and engineering enrollment and graduation trends, and Joan Burrelli, Senior Analyst in the NSF Division of Science Resources Statistics, discussed some of those data from the perspective of aerospace science and engineering.[1] She noted that cyclic trends in aerospace engineering employment are among the most pronounced in all of the natural science and engineering fields.

As with all natural science and engineering enrollment, first-time, full-time, graduate enrollment in aerospace engineering and space science mirrors unemployment trends. Higher unemployment in general encourages graduate enrollment, because students are more likely to elect to stay in or enter graduate school when they cannot get jobs. Despite the concern about a precipitous decline in applications from foreign students after 2001, 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 date available). Increased graduate enrollment by U.S. citizens and permanent residents more than compensated for the reduction in foreign students.

Burrelli 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 and 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 in real numbers as well as in comparison to non-U.S. enrollment in the same fields.

The NSF data show that bachelor's degrees granted each year in all natural science and engineering fields taken together have been increasing since 1991 and are at an all time high. Bachelor's degrees granted each year in aerospace engineering and space science have followed an upward trend since the slump in the late 1990s, but they have not recovered to the peaks that occurred in the late 1960s (during the Apollo era) or in the mid-1980s through early 1990s (during the defense buildup and the early years of the Strategic Defense Initiative). The number of students enrolled in aerospace engineering is small compared to the numbers enrolled in other specialties such as electrical and mechanical engineering.

[1] Links to key NSF databases can be found at <www.nsf.gov/statistics/>.

To illustrate the complexity of the problem of relating graduation trends to occupational trends, Burrelli used NSF data to make a rough comparison of the population of aerospace engineering and space science[2] degree holders with the number of degree holders actually working in those fields in 2003. In that year there were approximately 350,000 degree holders in aerospace engineering and space science. However, a significant majority of those degree holders, 270,000 or 77 percent, were not employed as aerospace engineers or space scientists. Similarly, the data indicated that of the 200,000 workers employed as aerospace engineers or space scientists, about 120,000 did not hold degrees in those fields. Consequently, 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 management. The committee notes that this situation illustrates the difficulty of identifying and filling workforce categories. It also illustrates the point that people with strong technical backgrounds can quite readily acquire the specialized knowledge to go into different (but related) fields. Consequently, recruitment need not be too tightly targeted to the momentarily required specializations.

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 still has been 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 when the employment picture softens.

BUREAU OF LABOR STATISTICS LABOR FORCE PROJECTIONS

The Bureau of Labor Statistics (BLS) periodically makes projections of the U.S. labor market, including the future size, industrial composition, and occupational distribution of the labor force. The projection process involves six steps, which address the following:

1. Size and composition of the labor force (starting with Census Bureau data and considering participation rates based on recent trends),
2. Growth of the aggregate economy (derived from multivariable macroeconomic models),
3. Allocation of gross domestic product by consuming sector and product,
4. Inter-industry relationships,
5. Industry output and employment, and
6. Occupational employment.

At the committee's February 22, 2006, meeting Nicholas Terrell from BLS discussed recent graduation and employment trends in selected areas of engineering and physical science, and he summarized the most recent BLS projections, which were released in 2004 for the period 2004 to 2014. Terrell noted that the number of bachelor's and master's degrees awarded in aerospace engineering and in physics and astronomy has been increasing since 2000, while the number of Ph.D. degrees granted over the same period has stayed relatively flat. BLS projects an 8 percent growth in total employment between 2004 and 2014 for aerospace engineers and 7 percent growth for astronomers and physicists, compared to a projected 21 percent increase for the total of all science, technology, engineering, and mathematics occupations. (See Table 3.1.)

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[2] To estimate the number of space science degree holders Burrelli used data for atmospheric sciences, physics, and astronomy. This number is small compared to the number of aerospace engineers and constitutes only about 10 percent of the total number of aerospace S&E workers.

TABLE 3.1 Total Employment in 2004 and Projections for 2014 in Selected Fields

	Employment (thousands)		Growth Rate (%)	Total Job Openings (thousands)
	2004	2014		
Total, all occupations	145,612	164,540	13	54,680
Science, technology, engineering and mathematics occupations	6,988	8,468	21	2,797
Aerospace engineers	76	82	8	25
Electrical and electronics engineers	299	331	11	91
Computer hardware engineers	77	84	10	20
Astronomers and physicists	16	17	7	6

SOURCE: Daniel E. Hecker, Occupational employment projections to 2014, *Monthly Labor Review* 128(11): 70-101, 2005.

Assessment of the accuracy of projections is important to determine how much they should be relied on for policy analyses. The occupational classification system used for the Current Population Survey was relatively consistent between 1979 and 2000, so that rough assessments of the past success of the projections can be made. For five BLS projections issued between 1979 and 1988, the committee compared the percentage change projected by BLS with the actual change in employment over the period for three occupations—aerospace engineering, electrical engineering, and mechanical engineering.

The committee found that the BLS employment projections exceeded the actual employment totals in all three fields in all five cases. The projections for electrical and mechanical engineering tended to be closer to the actual figures, but still overly optimistic in terms of anticipating greater demand for these occupations than actually materialized. For the period 1988 to 2000, employment in mechanical engineering was projected to grow by 20 percent but actually grew by 16 percent, while for electrical engineering the projections and actual figures were 40 percent and 29 percent, respectively. However, for aerospace engineering for the same period the employment change was projected to be 13 percent but actually was −33 percent.

In the committee's view, BLS projections are, at best, *estimates* of what will happen. The projections are particularly poor at dealing with recessions and rapid changes in particular industries and occupations. This was evidently the case with the projections for aerospace engineering, which were unable to anticipate or take account of the consolidation of the industry that took place in the 1990s. Furthermore, the BLS classification of occupations probably is not as detailed as required by NASA. All aerospace engineers are lumped together, and specialties such as systems engineering are not identified at all.

BOOZE ALLEN HAMILTON STUDIES ON THE SPACE INDUSTRIAL BASE

John Williams, senior associate at Booz Allen Hamilton, explained the results of two studies that the company had conducted for the Office of the Secretary of Defense and the National Reconnaissance Office in the early 2000s—the Space Industrial Base Study (SIBS) and the Space R&D Industrial Base Study (SRDIBS)—as well as findings from a 2004 Aerospace Workforce Review conducted by the National Defense Industrial Association (NDIA). 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 study identified workforce issues as being especially critical. Competition was found to be increasing for a limited number of available scientists and engineers. The subsequent

SRDIBS reported some easing in the competition for scientists and engineers that had been created earlier by the "dot-com" expansion, but concern about attracting, retaining, and training new workers in critical skills was seen as a continuing or growing problem. The NDIA review was described as being consistent with the earlier studies, with nearly 10 percent of job vacancies being unfilled. As with the two prior studies, certain specific skill areas, such as systems engineering, optical design engineering, and software engineering, were identified as being particularly critical and difficult to fill.[3]

In summarizing the workforce assessment aspects of these studies, Williams noted that while he saw no immediate crisis, there are problems present today, and the longer-term trends are disturbing. He pointed to the volatility of the national security space market as a particular obstacle to predicting the skills demand beyond the near term. Williams did emphasize that transferring key skills that come from experience from the Apollo generation to younger workers was a most important challenge.

DEPARTMENT OF DEFENSE PERSPECTIVES ON THE S&E WORKFORCE

William Berry, Acting Deputy Secretary of Defense (Laboratories and Basic Sciences), provided a Department of Defense (DOD) perspective on the S&E workforce. He described a situation in which potential employee interest and supply are falling while demand is increasing, but he noted that the data and predictive models on which to base firm conclusions are not especially robust.

The Defense Department requires that its in-house scientists and engineers be U.S. citizens who are eligible to receive security clearances. The DOD currently employs 43 percent of all the scientists and engineers in the federal government. In 2002 that included 27 percent of all federal scientists (a substantial fraction of which 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 in 2002.

The current DOD civilian S&E population is aging. In 1985, 33 percent of all the DOD scientists and engineers who held Ph.D. degrees were over 50, but in 2005 that number had increased to 57 percent. Berry noted that this increase attests to the fact that hiring has not kept pace with attrition in the ranks.

Current DOD projections based on the Defense Department's budget plans through 2025 indicate the need for hiring 15,000 scientists and engineers over the next decade. This is an increase of 16 percent in the demand by 2012. The DOD believes, based on BLS projections, that the supply of (security clearance eligible) scientists and engineers in the areas of need for the DOD will not be sufficient. For example, Berry showed BLS projections for increases in total employment demand between 2004 and 2014 of 43 percent for software engineers, 26 percent for computer and information scientists, and 16 percent for atmospheric and space scientists. However, projections of the supply are flat in many disciplines of interest to the DOD. Consequently, the DOD believes that it must engage in a comprehensive strategy, which encompasses K-12, undergraduate, and graduate levels, to attract more U.S. citizens into the technical fields of national security interest. Berry emphasized that recruiting from the underrepresented minority population of the workforce will also be critical. He explained that women and members of ethnic minority groups, when taken together, are in terms of numbers the majority of the potential workforce. However, they are significantly underrepresented in the current science and engineering workforce. Berry stated that national competitiveness and economic security require that the government do a better job of encouraging these groups to pursue careers in science and engineering.

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

COMMISSION ON THE FUTURE OF THE U.S. AEROSPACE INDUSTRY ASSESSMENT

John Douglass, the President and CEO of the Aerospace Industries Association and a member of the Commission on the Future of the U.S. Aerospace Industry, highlighted the commission's conclusions on workforce issues. The aerospace industry comprises three main segments—civil aviation, military systems, and space systems. The size of the overall aerospace workforce declined from 1990 through 1995 and remained more or less flat from 1995 through 2005. The aerospace fraction of the total U.S. S&E workforce fell from about 30 percent in 1965 to 2 to 3 percent in 2002. One of the commission's major recommendations was that "the nation [should] immediately reverse the decline in, and promote the growth of, a scientifically and technologically trained U.S. aerospace workforce."[4] Douglass stressed that federal investment in research and development is a critical part of the solution to the workforce problem, and he noted that there has been an increase in support for R&D, especially within the DOD.

INDUSTRY PERSPECTIVES ON THE FUTURE AEROSPACE WORKFORCE

Arnold Aldrich, Director of Program Operations at Lockheed Martin Corporation, provided a view from industry as seen from the Lockheed Martin. The overall aerospace workforce fell by 48 percent between 1990 and 1995, and it remained flat from 1995 to 2004. Citing BLS figures, Aldrich noted that the current industry workforce age distribution is bimodal, with the highest percentages of workers being those in the early years of their careers or else those over 40. This differs from the distribution of NASA's employee population (see Chapter 2), which is mono-generational and is skewed toward age 40 and above.

Aldrich reported that hiring at Lockheed Martin is currently not a problem and that it is consistent with replacement needs for retiring personnel. The company has been able to attract quality entry-level personnel. The fact that the company is large and has a national presence may be a factor in its ability to attract a workforce, whereas smaller, locally situated companies with unique specialties may have a more difficult time.

Aldrich discussed the injection of workers who are over age 50 into the workforce where they can embark on second careers. He noted that as a consequence, the projected retirement "cliff" with accelerated departures of older workers appears not to be happening. Instead there is an increasing trend toward delayed retirements, and the size of the over-55 workforce is expected to increase. National trends toward escalating health care costs and eroded wealth may contribute to delayed retirements.

With respect to meeting future workforce demands, Aldrich said that the current situation is stable and that projections of widespread shortages may be overstated. However, he noted that shortages may be developing in some particular skill areas in aerospace engineering, computer science, and electrical engineering. Furthermore, there is the potential for workforce demand to exceed supply within the next 5 years. Projections show that requirements are rising while undergraduate enrollments are flat or declining.

Aldrich turned to the subject of an emerging global workforce. An international workforce is strengthening, both in numbers and in skill levels, and it offers workers who are one-third to one-fifth less expensive than U.S. workers with the same skills. Relief on H1-B visa restrictions would enable the U.S. market to take advantage of some of the foreign nationals. Industry needs to be able to tap the offshore workforce to remain competitive. At present, implementation of export controls and State Department licensing under International Traffic in Arms Regulations (ITAR) pose a significant impediment to tapping the offshore workforce.

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[4] 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, p. xvi. Available from the U.S. Department of Commerce, Washington, D.C.

Amplifying on a point stressed by Berry, Aldrich noted that a diverse workforce will be very important to future business success. The minority workforce pool is growing, and opportunities for minorities and women need to be enhanced.

GENERAL CONCLUSIONS

The committee draws several general conclusions from the data and perspectives summarized above, as follows:

1. Although there are currently some problems in meeting demand, particularly for specific skills, the situation for major employers such as the DOD and the large aerospace companies is not now a major problem.[5]
2. Data on employment demand are difficult to obtain, particularly broken down by relevant skill areas, and those data and projections that exist are often ambiguous as one looks beyond the near-term future.
3. Most longer-term projections do forecast a gap between supply and demand that is larger than exists today. However, the size and the scope of the gap are not clear.
4. The problems with meeting future demand in the DOD are influenced by the need to employ U.S. citizens and permanent residents who can obtain security clearances.
5. NASA's workforce pool will be constrained in a fashion similar to the DOD's to the extent that NASA must hire people who can work in areas controlled by ITAR.
6. NASA's mono-generational employee age distribution (see Chapter 2) is different from the distribution seen for the DOD and industry, both of which were described at the workshop as being either bimodal or more nearly like the distribution of the U.S. workforce as a whole.

[5] The committee notes that this does not contradict the conclusions of the recent National Academies' study *Rising Above the Gathering Storm* (see Chapter 1, footnote 3), which addressed the threat to U.S. economic competitiveness, not a current shortage of scientists and engineers for aerospace and defense needs.

4
Factors Affecting the Aerospace S&E Workforce

A number of workshop presentations and panel discussions at the January workshop concerned factors impacting the demographics of the aerospace S&E workforce. Three presentations summarized workforce studies outside the aerospace sector—military shipbuilding in the United Kingdom, information technology in the United States, and U.S. nuclear reactor programs—that might provide useful lessons for the committee's examination of NASA's needs. Other panelists took an integrative view of the workshop discussions and suggested a number of recurring themes that emerged.

SHIPBUILDING AS A MODEL FOR NASA PLANNING

John Birkler, a senior policy researcher at the RAND Corporation, discussed several RAND studies of shipbuilding in the United Kingdom that present illuminating parallels for NASA's workforce planning. The committee was particularly struck by the parallels between the United Kingdom's shipbuilding experience during the past decade and NASA's skill retention and believes that it offers valuable lessons for the space agency.

Birkler noted that planning for workforce transitions requires addressing complex issues and that NASA is not the first organization to face such a challenge. Among the challenging problems involved are such questions as how to size and sustain core skills, how to plan over the long term to sustain skills and match demand with supply, and how to plan over the short term to save the expenses of relearning. Ambitious R&D programs are seldom continuous, and demand for core assets varies over time.

Birkler suggested that military shipbuilding could be a useful model for space transport design. Aircraft carriers and submarines are nuclear-powered, they are filled with sophisticated electronics, they require ever greater design efficiencies to fit multiplying missions in a constrained volume, they emphasize safety, and they are expensive. After the end of the Cold War the United Kingdom stopped producing nuclear submarines for a decade. When it resumed production it experienced severe and expensive development problems. RAND was asked to determine the resources needed to sustain design capability, the start date for next design effort, what to do in the interim, and how production should be planned. The roots of the problem were a historical neglect of core skills. RAND found that U.K. defense policymakers did not pay close-enough attention to nor act on long-term needs. Rather, government technical and program management skills atrophied, too much responsibility and risk were shifted to shipbuilders, and the shipbuilding industrial base was treated with a laissez-faire economic attitude.

Birkler noted several options for sustaining a design core workforce over a period during which there is a gap in demand—namely continuous design improvement (spiral development), continuous development of conceptual designs, employment on related projects, or collaboration with other countries or multinational entities. He emphasized that proper planning for the shorter term can lead to substantial savings through careful scheduling that can be invested in preserving core assets. One option for NASA might be to adjust its plans for the exploration vision based not only on budgetary concerns, but also on the need to maintain expertise that might be lost if there are significant gaps between the ending of major development projects and the start of new ones.

Birkler offered several lessons learned from the studies for the U.K. Ministry of Defense. First, managing workforce transitions requires (1) careful analysis of the time series of demand for labor, down to the skill level, (2) identification and characterization of core capabilities, and (3) long-term planning for the maintenance of those capabilities. Second, ignoring the complexities runs the risk of unnecessary expenditures for relearning, program demands for labor exceeding the supply, and loss of core capabilities.

INFORMATION TECHNOLOGY AS A PARALLEL FOR NASA PLANNING

Burt Barnow, Associate Director for Research at the Johns Hopkins University Institute for Policy Studies, drew several lessons from the work of the NRC Committee on Workforce Needs in Information Technology, which issued a report in 2001.[1]

The demand for information technology (IT) workers was growing rapidly in the 1990s, leading to controversy over whether the United States could meet industry needs. Some members of the IT community argued that there was an IT workforce problem, including claims that not enough graduates were being produced by U.S. colleges and universities in computer-related fields and that secondary school and postsecondary students in the United States were poorly prepared in math and science, compared with students in other countries. But other observations suggested that there was not a problem—that, for example, older IT workers might be available who had been previously discriminated against in terms of hiring, compensation, promotion, and access to retraining opportunities and that workers in IT come from a broad range of disciplines and backgrounds, not only math and science, so that the actual pool of workers might be considerably larger than the industry describes. The NRC committee found that:

- The IT labor market is complex and dynamic: occupations change content, and the needs of industry change rapidly;
- Government labor market data often do not tell us enough about the current labor market;
- There are a number of important dimensions to the IT labor market;
- Mechanisms by which workers acquire skills and employers accept them are not that clear; learning on the job is best; and
- In the IT workforce are many workers who do not have IT degrees.

Barnow offered several lessons applicable to the current study of workforce capacity to implement the vision for space exploration, including the following:

- Circumstances can change rapidly; the IT bubble burst less than 2 years after completion of the NRC's IT workforce study.
- The time period to be analyzed and the occupations of interest need to be defined as precisely as possible; assessments that look forward a shorter period into the future provide more accuracy.
- Competitors for the workers of interest are an important consideration.
- Different attributes of government, private, and international sectors are also important.
- To the extent that projections must be used, the track record of past projections should be examined, especially to see if there were systematic errors.

[1] National Research Council, *Building a Workforce for the Information Economy*, National Academy Press, Washington, D.C., 2001.

NUCLEAR REACTOR PROGRAM AS A PARALLEL FOR NASA PLANNING

Gerald Kulcinski, Associate Dean for Research for the College of Engineering at the University of Wisconsin-Madison, drew a comparison between the U.S. nuclear reactor program and NASA's program. Among the parallels, he noted that both peaked 30 to 40 years ago, both are currently experiencing a modest to significant revival, both look for international collaboration, both are experiencing "competition" from abroad, and both look to significant S&E human resource expansions for success. Furthermore, NASA will need a healthy nuclear engineering community as exploration moves to Mars and beyond, and nuclear systems have played an important role in NASA's robotic interplanetary exploration program.

Kulcinski said that an effect of re-licensing commercial nuclear reactors, which is now beginning to occur, will be to require a larger technical human resource base. Consequently, there are now estimates of growing gaps between nuclear engineering needs in the fission nuclear power industry and the number of graduating B.S. and M.S. students. However, university undergraduate enrollment has recovered since 2000 to early 1990 levels.

Kulcinski noted that increased Department of Energy funding of nuclear engineering (along with diminishing opposition from mainstream environmental groups) has been a major factor in the rise in undergraduate enrollment.

A PERSPECTIVE FROM U.S. UNIVERSITIES

Jack Burns, a professor of astronomy in the Department of Astrophysical and Planetary Sciences at the University of Colorado, Boulder, discussed five factors that will affect the extent to which U.S. universities will be able to meet their obligation to provide the necessary training for the aerospace S&E workforce. First, U.S. state-supported public universities are being increasingly stressed as state governments debate whether the universities serve primarily a public or a private good. State support is dwindling dramatically, a decline that is leading to a lack of flexibility, which increasingly hampers the universities' ability to respond to changing priorities and levels of national support for areas such as space research. University administrators are no longer willing to commit faculty positions and other resources to unstable programs.

Second, there is a need to re-evaluate the role of research universities in the increasingly global environment. Burns called for strengthening university curricula in social sciences and humanities (e.g., languages, history and culture, religious studies, political science), contributing to diversifying the workforce (including recruiting and training more women and persons of color in S&E disciplines). He also cited the need to stimulate both interdisciplinary research at the cutting edge at the interfaces between disciplines and multidisciplinary education (e.g., business, law, IT) so that students will receive more than narrow training in just science or engineering. Third, he noted that the expansion in biotechnology and the effects of doubling of the National Institutes of Health budget are having an impact on the physical sciences, including NASA programs. NASA's flat or declining sciences budget could result in entire subfields going away.

Fourth, Burns noted that student recruitment is a complex topic. By way of example he cited the University of Colorado undergraduate astronomy program. The program now has an enrollment of 150 undergraduate astronomy majors, which is a particularly robust program. Fifty percent of those students are on a teacher education track. Thus students do pay attention to job prospects and local market forces; half of the astronomy students see a major in astronomy as an attractive way to pursue a career in education rather than in a more technical application of their training.

Finally, Burns called attention to the impact of implementation of export controls and International Traffic in Arms Regulations (ITAR). This issue continues to grow for universities as more foreign students seek opportunities to work on spacecraft experiments and as U.S. investigators seek to pursue collaborations with European researchers. Some universities have given up resisting the government on these issues and have elected to bar non-citizens from participation in their space research activities on campus. Complying with ITAR requirements is an even bigger issue for university scientists' industry collaborators.

INDUSTRY PERSPECTIVES

At the committee's February 22 meeting, committee member John W. Douglass, President and CEO of the Aerospace Industries Association (AIA), briefed the committee on the views of a sampling of AIA members on the workforce issue. Douglass said that for the short term, NASA has the human capital necessary to implement the exploration vision, but that AIA is concerned about the agency's systems engineering and program management experience. In addition, many NASA engineers do not have program start-up experience, and any delays in the Crew Exploration Vehicle program will likely increase attrition. In the longer-term, NASA will probably have a shortage of experienced engineers. Douglass said that there is a danger that the agency cannot compensate NASA engineers sufficiently to compete with industry. Industry also has the human capital to implement the exploration vision in the short term, but in some key technology areas the skill sets are only "one or two people deep." Douglass also stressed that the longer-term outlook is good as long as the exploration vision remains stable and federal funding continues.

Douglass said that the skills necessary for research, development, technology, and engineering are "not necessarily similar" to those required for operational needs. In addition, insufficient lead times for contractors and subcontractors do not allow the appropriate skill sets to be in place. Canceled jobs lead to attrition to other non-aerospace industry projects. He added that ITAR hampers U.S. companies possessing a multinational workforce and that the agency should resolve discrepancies between State Department and NASA interpretation of ITAR. In addition, Douglass recommended that NASA should look at industry practices as a model to train and transfer skilled workers to meet current priorities, develop a mentoring program utilizing the current and retired knowledge base, develop a program management and systems engineering and integration training program, create a transition plan by mapping needed skill sets, and look at ways to supplement its workforce from outside sources.

Ray Haynes, Director for University Alliances and Development of the Office of the Chief Engineer at Northrop Grumman Space Technology, spoke to the committee on February 23, presenting his company's view of the challenges of engineering development in a rapidly changing global environment. Haynes stated that the aerospace industry as a whole faces a shortage of engineers. Citing AIA figures, he stated that February 2004 represented a 50-year low in aerospace employment. It is now increasing, but the talent pipeline is insufficient. Currently 9 percent of funded positions are going unfilled, and a significant fraction of the current workforce will be eligible for retirement by 2008.

According to Haynes, university research is a key factor for future success, because corporate research and development laboratories have downsized and government laboratories are focused on Department of Defense (DOD) research. Education collaboration between industry, universities, and government is required for success, and U.S. government investment support is critical. Haynes submitted that engineering education and university research should focus on basic and emerging engineering needs. For example, because nanotechnology is emerging as a new field, it offers an opportunity for the United States to retain its lead in high technology, but it will require massive investment in new technology now.

Steve Oswald, vice president and program manager of the space shuttle program for Boeing, briefed the committee on February 23. Oswald explained that there were a number of important "success factors" for the transition from shuttle operations to crew exploration vehicle (CEV) development. He said that an important factor will be the ability to share the skilled people between the Space Shuttle program and the Crew Exploration Vehicle and Crew Launch Vehicle programs. He said that how NASA contracts for products and services can make the transition easier, or more difficult. He said that one way that Boeing was looking to do this was to bring back recent retirees to work on the space shuttle while moving some of the shuttle workforce to new projects. He stated that NASA's decision to base the future CEV and a heavy lift launch vehicle on existing shuttle components significantly eased the problems of transitioning the workforce. Without that decision, the company would have to lay off employees much sooner. Boeing is also working on developing a space shuttle mentor-protégé program. The company has developed an "intellectual capital planning tool" that was instituted in Houston in January 2006 and will soon be used in other Boeing facilities in Florida; Huntsville, Alabama; and Huntington Beach/Palmdale, California.

RECURRING THEMES

The final session of the January workshop was devoted to a synthesis of the major themes and issues that emerged from the meeting. In opening the discussion, Roy Torbert, a professor of physics in the Institute of Earth, Oceans, and Space at the University of New Hampshire, commented that there was not yet a clear sense of the problem. He suggested that the central problem might be NASA's need for engineers and managers who have experience on real projects. If that is the case, then it implies a significant need for training the in-house workforce.

Don Giddens, Dean of the College of Engineering at the Georgia Institute of Technology, noted that NASA faces a dilemma. On the one hand, the agency seeks to shift its workforce to more in-house design and systems integration and to build the skills needed in the next 10 years to support human exploration. However, NASA has very limited hiring opportunities due to budget constraints, excess capacity in the current workforce, and a desire to use layoffs only as a last resort. Consequently, with too many of the wrong people and limited ability to hire the right people, NASA will be hard-pressed to attract students if the message is that there are no jobs. Looking outside NASA, Giddens observed that workforce issues are particularly complex. The data on whether there are too many, too few, or the right number of S&E graduates are unclear; the roles and needs of large companies, small companies, and universities are distinct; industry globalization, recruiting from the minority workforce pool, and requirements to hire U.S. citizens in some sectors all have impacts.

These issues led Giddens to suggest that there are several important tasks for NASA, including the following:

- Getting definitive data on near-term and long-term workforce skill needs as a function of time (e.g., in the manner described by Birkler for the RAND study of U.K. shipbuilding);
- Addressing the current mismatch between NASA workforce skills and projected needs;
- Retraining the current workforce and using targeted recruitment (e.g., via co-ops);
- Initiating staff reductions;
- Looking beyond 2011 to assess which skills will be obtained through evolutionary change and which (if any) will require revolutionary efforts;
- Attracting experienced, mid-career S&E workers from the private sector in the "right" skill sets (e.g., in systems engineering and project management);
- Revisiting in-house versus contractor roles (especially because industry has more flexibility to hire and change its workforce makeup); and
- Considering more or different NASA efforts to affect the supply side of the workforce.

Looking at the broader national picture, Giddens offered three thoughts. First, too much centralization in national workforce planning is probably counter-productive and should be avoided. Second, a strength of U.S. higher education is its diversity in terms of its capacity to create opportunities for minority students and to offer exposure to a wide range of disciplines; that should be nurtured. Third, a strength of U.S. industry has been the (federal and private) investment in R&D; a decline in this investment poses a threat to innovation in the United States.

T.K. Mattingly, a former Apollo and shuttle astronaut and aerospace executive, suggested that launch vehicles and spacecraft are now mature technologies. NASA's human spaceflight programs have recently concentrated on operation of the shuttle and assembly of the International Space Station, rather than the development of new vehicles and systems. The skills needed for operations are not the same as those needed to accomplish development of the systems needed to implement the vision for space exploration. To get those necessary skills will require people with experience, and this may require a concentrated effort to prepare systems engineers and project managers. To succeed in the environment of cost constraints, the future design teams will need people who have experience managing cost and schedule as well as technical work.

Mattingly, and others, also argued that recruiting people to implement the exploration vision will require convincing them that the work is interesting, important, and challenging. Success will require passionate people who will be able to believe that the exploration vision will be sustained.

During the concluding plenary discussion, participants raised a number of points to amplify or expand on the workshop panelists' comments. Key points included the following:

- NASA's attention to workforce issues seems primarily internally focused, but a more outward-looking approach is desirable that accepts that industry and academia are integral parts of the workforce.
- A solution to NASA's near-term problems will not come via training students because that is too long a process. Instead, exchanges with industry and academia are more promising for the near term.
- There will be a need for more organizational transparency to promote the flow of workers between NASA, industry, and academia.
- Workforce pull will be more important than push; jobs will have to be made attractive to appeal to workers.

KEY FACTORS

The committee has drawn on the presentations summarized above, and the attendant discussions by participants at the workshop, to distill a set of factors that will influence the demographics of the future aerospace S&E workforce. They are enumerated below.

Perception

Potential employees need to be convinced that the vision for space exploration is an exciting effort, that it is sustainable, that they can play an important role, that they can receive training or experiences that will help in future jobs, and that their potential co-workers and managers are committed. Furthermore, potential employees will need to be convinced that the state of all of the above will be better than that for non-vision-for-space-exploration aerospace positions and not worse than that for other, non-aerospace jobs.

Stability

A key question is whether the overall size of the effort will be sufficiently large to maintain constant staffing, or whether there will be "seasonal workers." If cycles of high and low demand are anticipated, potential employees will want to know how those cycles are accounted for. It will also be important to know whether there are reachable and significant milestones that can serve as jumping-off points for both employees and employers. A related factor is not simply how the project is perceived by potential employees, but also how it may be perceived by the institutions that provide the employees, such as university engineering and science departments and university-based institutions. Students' career paths are shaped by their advisors, and if the advisors perceive NASA to be a bad career choice, this will affect their students' decisions. As one workshop participant noted, if prospective employees believe that they lack assurance that the space exploration vision is stable enough for them to build a substantial portion of their career working for it, then the situation is unstable.

Availability

Key vacancies need to be open for competition (thereby creating an environment that encourages and facilitates the movement of NASA employees into industry for developmental work experience assignments, the movement of industry employees into NASA where they can mentor NASA employees, and the subsequent return of these employees to their original institutions). NASA and industry need to be properly matching applicants and vacancies, providing reasonable assurance of upward mobility and quality training, and properly identifying internal solutions to vacancies.

Recruitment

Recruitment will be influenced by whether NASA and industry can properly identify required skills in advance. Whether the workforce has reliable feeder programs and whether feeder programs can help respond to identified needs will have an impact. Paying the appropriate level of attention, expanding the diversity of the workforce, and recruiting from underrepresented populations will be especially important. Furthermore, the extent to which the industry is attracting elite workers will have a feedback effect on recruitment.

Retention and Engagement

Key factors include the ability to pay competitive salaries, maintain employees' sense of usefulness, prepare employees for future contributions in addition to current contributions, listen to inputs from employees, provide mentors and training, including hands-on experience development opportunities, and explicitly facilitate the transfer of know-how from senior to younger employees.

International Involvement

Although constraints imposed by ITAR may lead to a higher demand for U.S. citizens and permanent residents in NASA's workforce than might be the case in other employment sectors, international participation in space exploration will still have a significant impact. For example, the workforce for NASA will be influenced by what skills, jobs, and salaries are being provided by foreign partners and how completely those are integrated with domestic equivalents.

5
Findings and Recommendations

The committee heard briefings about NASA's ongoing process of characterizing the skills of the current NASA civil service staff and assessing the mix of skills that NASA will need to implement the exploration vision. The committee recognizes the difficulty of this task and appreciates the efforts by NASA to date. **NASA has made a reasonable start on assessing its near- and long-term skill needs, and the committee shares the view expressed by NASA representatives that there is still much more work to be done. However, NASA's work has focused on initial assessment of current workforce demographics and estimates of future needs. NASA has not yet translated that analysis into a strategy and action plan. NASA's lack of work to date has limited the committee's ability to assess exactly what needs to be done.**

The workforce issues that NASA faces as it moves to implement the vision for space exploration are varied and are dependent on the timeframe in question. Over the next 5 years NASA needs to meet the challenge of two new major development programs while phasing out the space shuttle. In the longer term, NASA will have to learn to structure its workforce in accord with a model of the required makeup of that workforce rather than to simply let it evolve. This shaping needs to be done in a manner that will ensure that the agency always has an in-house staff with the appropriate skill mix to guide and manage future major development projects effectively, as well as to ensure that longer-term needs are not put at risk by near-term personnel actions. A key factor in assessing whether NASA currently has the staff it needs is the "make/buy" ratio—i.e., the ratio of development work that will be performed inside NASA versus by contractors. The key is not just having enough employees in the right skill boxes, but also having people with adequate experience to do the job. **All of these considerations highlight a compelling need for NASA to develop a strategic workforce plan that deals with the next 5 years *and* to lay the foundation for a longer-term process that NASA has never before attempted and that is difficult to do, yet nevertheless is vital for the agency's success in implementing the exploration vision. The degree to which the agency chooses to perform work in-house versus by a contractor will play a major role in the number of personnel that the agency will require.**

The committee heard from many sources—including representatives of NASA, the Department of Defense (DOD), academia, and industry—that there may be shortages of qualified employees in specific skill areas and that there are concerns over whether the experience base in the current workforce is adequate to meet current and expected future needs in those selected areas of expertise. **However, the committee has seen no compelling evidence of a looming, broadly based shortage in the supply of aerospace S&E workforce employees to meet NASA's needs.**

The most frequently cited critical skills are ones that are acquired via real-work experience. Many of those who spoke to the committee cited systems engineering as an example of the type of skill that can only be perfected on the job. A number of venues and programs outside NASA are already in place and probably available to NASA, and there are opportunities for non-NASA experts to serve in mentoring assignments inside NASA. To be effective development or mentoring strategies, both kinds of exchanges will have to include hands-on work opportunities. The committee understands that ethics laws and conflict-of-interest constraints can pose obstacles, as can a lack of availability of training and competitive compensation. Also the necessary programs to respond to the need to enhance and expand the skills of the NASA workforce will require explicit resources, management commitment, and NASA-industry collaboration and coordination. **Nevertheless, to address those skill areas where there are**

potential shortages (both for the near term and the longer term), NASA needs to pay particular attention to identifying and expanding ways to promote exchanges of personnel between NASA and the non-government sector (industry, academia, and non-government organizations). The committee recognizes that this is difficult to accomplish, but believes that it is important to try to overcome the obstacles that prevent it from occurring.

The interest and the willingness of current and potential highly qualified employees to continue or to seek employment in space research and development depends not only on their passion for space exploration but also on their belief that it will offer them viable careers. Later recruitment will be especially challenging in areas where NASA curtails or terminates work in the near term, thereby handicapping or preventing later restoration of that workforce segment in, for instance, areas such as astrobiology, life sciences, and microgravity research. **The committee concludes that the ability to recruit and strategically retain the needed workforce will depend fundamentally on the long-term stability of the vision for space exploration and a sustainable national consensus on NASA's mission. Similarly, when NASA produces instability in the institutions that provide its workforce, as it is now doing in microgravity science, it creates a perception that space exploration is a bad career option.**

The committee makes the following recommendations:

1. **NASA should develop a workforce strategy for ensuring that it is able to target, attract, train, and retain the skilled personnel necessary to implement the space exploration vision and conduct its other missions in the next 5 to 15 years.** The agency's priority to date has been to focus on short-term issues such as addressing the problem of uncovered capacity (i.e., workers for whom the agency has no current work). However, NASA soon might be facing problems of expanding needs or uncovered capacity in other areas and at other centers. Therefore, it is important to develop policies and procedures to anticipate these problems before they occur.
2. **NASA should adopt innovative methods of attracting and retaining its required personnel and should obtain the necessary flexibility in hiring and reduction-in-force procedures, as well as transfers and training, to enable it to acquire the people it needs. NASA should work closely with the DOD to initiate training programs similar to those that the DOD has initiated, or otherwise participate actively in the DOD programs.**
3. **NASA should expand and enhance agency-wide training and mentorship programs, including opportunities for developing hands-on experience, for its most vital required skill sets, such as systems engineering.** This effort should include coordination with DOD training programs and more use of exchange programs with industry and academia.

Finally, the committee wishes to stress that this is an interim report. The committee still has to complete its examination of the role that universities play in supplying, training, and supplementing NASA's workforce. Part of this assessment will be to consider the role that universities can play in providing hands-on space mission training of the workforce, including the value of carrying out small space missions at universities. The committee also plans to review the final version of NASA's Systems Engineering and Institutional Transition Team (SEITT) report. The committee will evaluate the skills that the study identifies as necessary to implement the vision for space exploration, assess the current workforce against projected needs, and identify gaps and obstacles to responding to NASA's projected needs. In its final report, the committee expects to develop recommendations for specific actions by the federal government, industry, and academia, including organizational changes, recruiting and hiring practices, student programs, and workforce training and improvement to enable NASA to accomplish the goals of the vision.

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 exploration vision, 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 (202) 358-2261 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
Workshop Agenda and Participant List

AGENDA

January 23, 2006

10:00 a.m. Session 1: Welcome and summary of goals of the workshop — Moderator: D. Black

NASA introductory remarks (S. Pace)

- Overview of the Vision for Space Exploration
- NASA's needs and expectations for the study

NASA's exploration plans and systems architecture (M. Hecker)

- Major goals, elements, segments, and time line
- Roles of NASA centers, industry, and academia
- Top-level workforce implications

NASA's space and Earth science plans and directions (K. Ledbetter)

- Major goals, elements, segments, and time line
- Roles of NASA centers, industry, and academia
- Top-level workforce implications

12:30 p.m. Lunch

1:30 p.m. Session 2: Survey of relevant data and prior studies — Moderator: R. Colladay

Broad assessments of the U.S. S&E workforce

- National Science Foundation studies of enrollment and graduation trends (J. Burrelli)
- RAND Corporation studies (J. Birkler)
- National Research Council studies (B. Barnow)

Roundtable discussion with presenters and all participants

Assessments of aerospace workforce issues

- Booz Allen Hamilton study for the National Reconnaissance Office (J. Williams)
- Aerospace Commission study (J. Douglass)
- NASA studies
  —In-house studies (T. Dawsey)
  —NASA Advisory Committee study (G. Kulcinski)
- Roundtable discussion with presenters and all participants

5:30 p.m. Reception and dinner

January 24, 2006

9:00 a.m. Session 3: Factors that are impacting workforce supply and demand: the current picture, trends, and projections — Moderator: K. Thornton

Perspective from industry (A. Aldridge, Lockheed Martin)

- Anticipated needs for technical disciplines, skills, and levels of training
- Experience and outlook regarding recruitment and retention
- Competition from other fields or sectors
- Policy and marketplace impacts
- International considerations, including the impact of export controls and national security constraints
- Adequacy of training options

Perspective from federal government (William Berry, Department of Defense)

- Anticipated needs for technical disciplines, skills, and levels of training
- Experience and outlook regarding recruitment and retention
- Competition from other fields and sectors
- Policy impacts
- International considerations, including the impact of export controls and national security constraints
- Adequacy of training options

Perspective from academia (J. Burns, University of Colorado, Boulder)

- Anticipated needs for technical disciplines, skills, and levels of training
- Experience and outlook regarding student recruitment
- Competition from other academic concentrations
- Policy and marketplace impacts
- Impediments to providing training in needed technical disciplines and skills
- International considerations, including the impact of export controls and national security constraints

Roundtable discussion with presenters and all participants

12:00 p.m. Lunch

1:00 p.m.	Session 4	Moderator: J. Rothenberg
	Panel discussion of recurring themes and key issues drawn from the prior sessions (D. Giddens, T.K. Mattingly, R. Torbert)	
	Roundtable discussion with all participants, including NASA representatives	
2:00 p.m.	Summary remarks by chairs	
3:00 p.m.	Adjourn	

PARTICIPANTS

Committee Members

Burt Barnow, Johns Hopkins University
David Black, Universities Space Research Association
John Douglass, Aerospace Industries Association
Daniel Hastings, Massachusetts Institute of Technology
William Pomerantz, X PRIZE Foundation
Joseph Rothenberg, Universal Space Network
Kathryn Thornton, University of Virginia

Speakers

Arnold Aldrich, Lockheed Martin
William Berry, Department of Defense
John Birkler, RAND Corporation
Jack Burns, University of Colorado, Boulder
Joan Burrelli, National Science Foundation
Ray Colladay, Lockheed Martin (retired)
Toni Dawsey, National Aeronautics and Space Administration
Don Giddens, Georgia Institute of Technology
Michael Hecker, National Aeronautics and Space Administration
Gerald Kulcinski, University of Wisconsin
Ken Ledbetter, National Aeronautics and Space Administration
Scott Pace, National Aeronautics and Space Administration
Roy Torbert, University of New Hampshire
John Williams, Booz Allen Hamilton

Guest Experts

Bill Adkins, U.S. House of Representatives Science Committee
Marc Allen, NASA
Portonovo Ayyaswamy, University of Pennsylvania
Jeff Bingham, U.S. Senate Commerce Committee
Sue Hegg, The Boeing Company
Terri Lomax, National Aeronautics and Space Administration
Adam London, VENTIONS, LLC
T.K. Mattingly, U.S. Navy (retired)

Richard Obermann, U.S. House of Representatives Science Committee
Trish Pengra, National Aeronautics and Space Administration
Marcia S. Smith, Congressional Research Service
Jean Toal-Eisen, U.S. Senate Commerce Committee

D
Committee Meeting Agenda, February 22, 2006

CLOSED SESSION

8:30 a.m. Committee organizational business

OPEN SESSION

10:00 a.m. NASA presentation on agency skills inventory and projections (J. Simpson et al.)

12:30 p.m. Working lunch: Presentation and discussion

Aerospace Industries Association presentation and discussion (J. Douglass)

1:30 p.m. Presentations and discussion

Bureau of Labor Statistics presentation and discussion (N. Terrell)
Bureau of Labor Statistics estimate assessment (B. Barnow)
Boeing perspectives (S. Oswald)
ASEE and Northrop Grumman perspectives (R. Haynes)

E
NASA List of Competencies and Current Agency Population

TABLE E.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
Data Systems and Technology	20
Intelligent/Adaptive Systems	78
Network Systems and Technology	224
Neural Networks and Systems	3

continues

TABLE E.1 *continued*

Competency	Count
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

TABLE E.1 *continued*

Competency	Count
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
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

F
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, he 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 impacting more than 2,500 students in both undergraduate and graduate programs. Northrop Grumman currently has over 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 AltVen 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 all of the foundation's new prizes in the field of aerospace. As an undergraduate, Mr. Pomerantz spent two summers at NASA's Goddard Space Flight Center, where he served as a research associate in the NASA Academy. After graduating, he worked as a planetary geologist studying martian geology in the laboratory of James Head III at Brown University. Mr. Pomerantz 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 networking tool for young space professionals around the world. Mr. Pomerantz is an officer of the Space Generation Foundation, a vice president of the NASA Academy Alumni Association, and a member of the Steering Committee for the Space Exploration Alliance.

JOSEPH H. ROTHENBERG is president and a member of the board of directors of Universal Space Network. From 1981 to 1983, he served as executive vice president of Computer Technology Associates, Inc., Space Systems Division, where he managed all ground test and operations systems-engineering projects. Those projects included the Hubble Space Telescope, the Solar Maximum repair mission, and space tracking and data system architecture projects. In 1983, he joined NASA Goddard Space Flight Center and became center director in 1995. He was responsible for 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. He is widely recognized for leading the development and successful completion of the first servicing mission for the Hubble Space Telescope, which corrected the telescope's flawed optics. Mr. Rothenberg served on the NRC Committee on Assessment of Options for Extending the Life of the Hubble Space Telescope (2004-2005).

KATHRYN C. THORNTON is a professor in the Department of Science, Technology and Society, and in Mechanical and Aerospace Engineering, at the University of Virginia and 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

JOSEPH K. ALEXANDER, study director, 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 Space Flight Center (1993-1994), and assistant associate administrator for space sciences and applications in the NASA Office of Space Science and Applications (1987-1993). Other positions have included deputy NASA chief scientist and senior policy analyst at the White House Office of Science and Technology Policy. Mr. Alexander's own research work has been in radio astronomy and space physics. He received B.S. and M.A. degrees in physics from the College of William and Mary.

DWAYNE A. DAY, SSB research associate, has a Ph.D. in political science from George Washington University and has previously worked for the Columbia Accident Investigation Board and the Congressional Budget Office.

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.