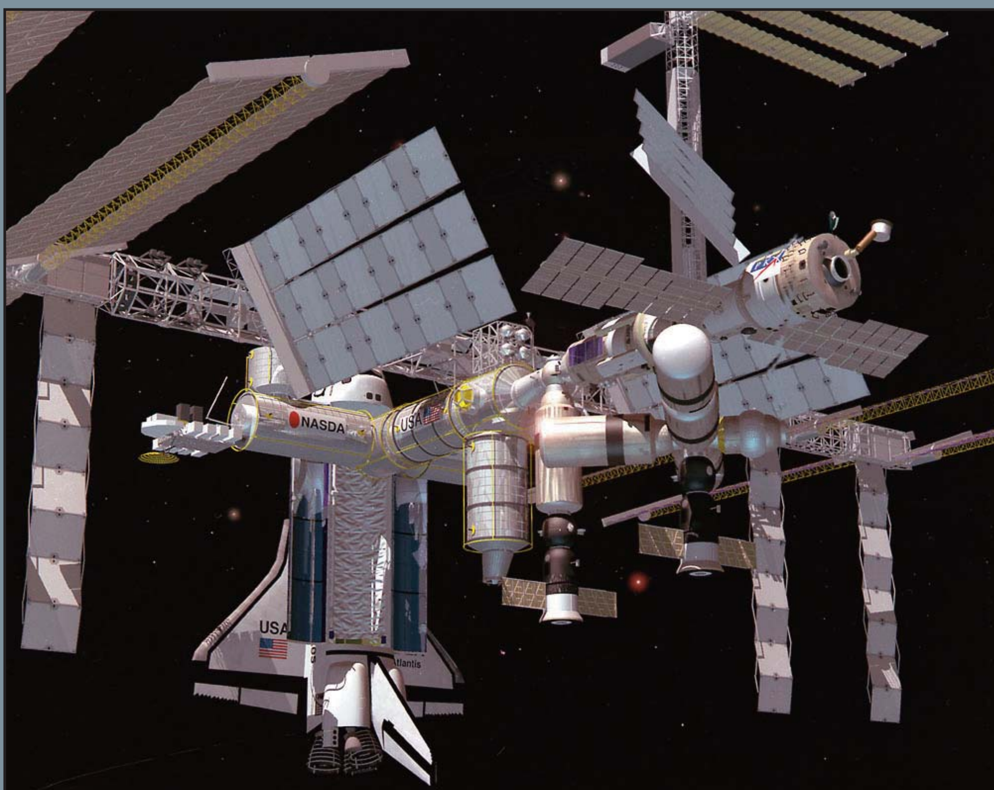
United States Space Policy: Challenges and Opportunities Gone Astray



George Abbey and Neal Lane

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United States Space Policy: Challenges and Opportunities Gone Astray

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Preface

Space has long been the setting of especially intricate encounters between human aspirations and the implacable laws of the physical universe. It is a natural laboratory of fundamental science, at once the source of seminal conceptual achievements and bewildering mysteries. It has been the venue for both spectacular feats of engineering and tragic accidents. It has been the locus of uplifting collaboration among nations as well as ominous confrontation. It is an ever-compelling template on which popular imagination plays out.

The resulting array of interests, attitudes, and emotions engaged in the practical utilization of space has made that topic an especially demanding problem of public policy. Because of the risks and expense involved in space operations, the burden so far has been borne primarily by the major national governments. And those governments have been driven primarily by national security considerations, the legacy of confrontations between the two global alliances that dominated the latter half of the twentieth century. The passing of that era and the progressive expansion of commercial utilization of space have clearly created a new situation but not as yet the decisive reformulation of basic purpose and operational policy that the change of circumstance can be expected to require.

There has in fact been an argument about the basic character of the appropriate adjustment. An impulse emerging from within the United States government to dominate the utilization of space for national military advantage has been resisted by a nearly universal coalition of other countries defending the principle of equitable utilization for common benefit. If the outcome were to be directly decided by simple majority sentiment, the argument would have long since been settled. Most people when asked opt for collaboration and the pursuit of common interest; redirecting the inertia of established policy is anything but simple, however. The underlying argument involves a collision of intense convictions, and casual endorsement of common interest is often mixed with the residual fear of imperial aggression that is an enduring product of historical experience.

The appropriate balance between collaboration and confrontation in the era of globalization is an unsettled question, and the implications for space policy have not been worked out in the necessary detail. The effort to do so is demanding, and will undoubtedly take some time.

To stimulate the broad discussion that must accompany any fundamental redirection of policy, the American Academy of Arts and Sciences initiated the Reconsidering the Rules of Space project in 2002. Six occasional papers have been published dealing with, respectively, the basic laws of physics that apply to all space activity (*The Physics of Space Security: A Reference Manual*, by David Wright, Laura Grego, and Lisbeth Gronlund, 2005); the fundamental issues of security policy (*Reconsidering the Rules of Space*, by Nancy Gallagher and John Steinbruner, 2008); the policies of the principal national governments (*United States Space Policy: Challenges and Opportunities*, by George Abbey and Neal Lane, 2005, and *Russian and Chinese Responses to U.S. Military Plans in Space*, by Pavel Podvig and Hui Zhang, 2008); the historical origins of China's space program (*A Place for One's Mat: China's Space Program, 1956–2003*, by Gregory Kulacki and Jeffrey G. Lewis, 2009); and a review of the European Union's collective efforts to address space security issues (*A European Approach to Space Security*, by Xavier Pasco, 2009).

United States Space Policy: Challenges and Opportunities Gone Astray is the seventh paper in this series, updating the 2005 publication by the same authors. It warns of serious misalignment of the purposes, operating principles, and resources of the U.S. space program. It notes that the announced intention to send manned missions to the moon and to Mars as virtually exclusive national ventures has not been adequately financed. As a result, most of NASA's activities are being redirected to those specific purposes, thereby jeopardizing its broader historical functions without assuring that the projected missions can in fact be accomplished. The paper recommends a significant rebalancing of priorities to support the international space station, to extend shuttle missions through 2015, and to continue NASA's traditional support for basic science and aeronautical engineering. It updates the 2005 assessment of impediments to a well-balanced space program, noting that export-control policies, decline in the science and engineering workforce, the state of mission planning, and the degree of international cooperation have all become more serious problems. Overall it provides an urgent appeal for fundamental reconsideration.

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United States Space Policy: Challenges and Opportunities Gone Astray

George Abbey and Neal Lane

In 2004, with his Vision for Space Exploration (VSE), President George W. Bush established a new course for the National Aeronautics and Space Administration (NASA) and America's civil space program.[1] VSE presented a bold plan to complete the International Space Station (ISS) and phase out the space shuttle fleet by 2010. The VSE program also envisioned designing and building a replacement for the space shuttle by 2008, flying it by 2014, returning human beings to the moon by 2020, and preparing for missions to Mars. In response to Bush's new vision, NASA quickly reset its priorities, pushing science, including environmental research, further down the list.

Critics of Bush's plan expressed a range of concerns and called VSE bold but incomplete and unrealistic. First and foremost among the critics' concerns is the mandate to stop flying the space shuttle in 2010. Grounding the shuttle fleet means the United States will depend on Russia for human access to space for at least four years, but more realistically for a decade. Bush and NASA also made clear that VSE would be an entirely U.S.-led effort.

In our paper, *United States Space Policy: Challenges and Opportunities*, published by the American Academy of Arts and Sciences in 2005, a year after Bush's announcement of his new vision, we spoke of U.S. space policy as presenting a paradoxical picture of high ambition and diminishing commitment.[2]

We contended that, to achieve the president's proposed manned spaceflights to the moon and to Mars, the United States would need to bolster the competitiveness of its commercial space industry, expand international cooperation, and refocus on basic science both in the space program and in the broader economy. We stated that the Bush administration's commitment to these elements had not been clearly expressed, and we identified some of the challenges facing the U.S. space program—notably, a decline in the competi-

1. George W. Bush, "Remarks by the President on U.S. Space Policy," press release, January 14, 2004, http://history.nasa.gov/Bush%20SEP.htm.

2. George Abbey and Neal Lane, *United States Space Policy: Challenges and Opportunities* (Cambridge, Mass.: American Academy of Arts and Sciences, 2005).

tiveness of the U.S. space satellite and launch industry (due, in part, to an overly restrictive policy on export controls) and a projected shortfall in the U.S. science and engineering workforce.

Under Bush's ill-defined space policy, government leaders made decisions about space policy that affected not only national security but also the ability of the United States to compete successfully with other countries in the commercial use of space and to maintain a leadership role in space exploration, science and engineering, and technology. These decisions have had ramifications for the health of the U.S. space industry, which is crucial to all aspects of the space program and fundamental to the future of American efforts in space. Furthermore, these policies were being made without adequate consultation with foreign partners, whose participation is essential to future U.S. space efforts.

Our 2005 paper addressed four serious barriers that would need to be overcome in order for the United States to realize the enormous potential of space science and exploration: 1) the negative impact of U.S. export controls on U.S. space commerce and international cooperation; 2) the projected shortfall in the future U.S. science and engineering workforce; 3) inadequate planning for NASA's future; and 4) the erosion of international trust and cooperation in space.

We stressed the importance of balance in NASA's programs, including the need for strong science, engineering, and environmental (for example, Earth-observation) research components—as well as human space exploration—and expressed concerns about the danger that the research programs would be cut back to make progress on VSE. We felt it was critical to the nation's future civil space effort that NASA not become a single-mission agency.

That was four years ago. Today not only are those barriers still standing, they are even more daunting because the significant political and economic changes that have occurred since our paper's publication in 2005 make the task of overcoming these obstacles even more challenging.

BACKGROUND

The October 4, 1957, flight of the Soviet Union's *Sputnik 1*—the first human-made satellite—was a turning point in the Cold War. The event startled the world and prompted great alarm in the United States, which had believed itself the world's leader in space technology and missile development. The surprise *Sputnik* launch and the failure of the first U.S. satellite launch attempt on December 6, 1957, provided an unwelcome wake-up call. The crisis spurred a number of U.S. initiatives, including the National Aeronautics and Space Act (Public Law 85-568), signed into law by President Dwight D. Eisenhower on July 29, 1958. The legislation created NASA, the civilian agency responsible for guiding the nation into the space age.

The Soviet Union followed the triumphant flight of *Sputnik* with other equally successful space missions, culminating in the flight of the first man in space, Yuri Gagarin, in April 1961. Nearly a year later, in February 1962, the United States achieved its first manned Mercury orbital flight, when John Glenn orbited Earth. Nine months prior to that flight, and immediately following American astronaut Alan Shepherd's suborbital Mercury flight, President John F. Kennedy had, on May 25, 1961, challenged the nation to send a man to the moon and return him safely to Earth by the end of the decade.

Such a feat would establish the United States as the world's unquestioned technological leader. The Apollo program, which will go down in history as one of the greatest human achievements, was on its way. In a little more than seven-and-a-half years, *Apollo 8* orbited the moon. The following year, six months later, *Apollo 11* landed on the lunar surface. The Apollo program captivated the imaginations of thousands of young people who would go on to become the nation's scientists, mathematicians, and engineers—a brain trust for U.S. industry that fueled American progress for decades.

The United States would expand its record of leadership in space with both manned and unmanned orbital and exploration missions. On July 20, 1976, the *Viking 1* spacecraft successfully landed on Mars, followed by *Viking 2* less than two months later. The results from the Viking experiments provided the most complete view human beings had ever had of the "red planet." Volcanoes, lava plains, immense canyons, cratered areas, wind-formed features, and evidence of surface water were all apparent in the Viking orbital images. The exploration of Mars continued with *Mars Pathfinder*, the first mission to carry a rover to a planet. The rover, Sojourner, landed on Mars on July 4, 1997, and went on to execute many experiments on the Martian surface. Two other successful Mars exploration rovers, Spirit and Opportunity, have continued to provide useful data on the planet almost continuously since their landings in 2003.

These and other planetary and astronomy missions, including the enormously successful Hubble Space Telescope, have completely changed our understanding of the universe in a human life span. The U.S Shuttle Transportation System, commonly referred to as the space shuttle, is the longest running, most successful fleet of manned space vehicles ever made, despite setbacks, including the tragic *Challenger* and *Columbia* shuttle accidents. The ISS, which involves close partnerships with Russia and thirteen other nations, is an incredible accomplishment. When the ISS is completed, it will represent the largest international cooperative technological project in history.

By and large, these were all programs of the 1970s, 1980s, and 1990s. Today, NASA, with VSE as its focus, has become an agency that is all about—some would argue only about—human spaceflight to the moon and Mars. Any other initiative has great difficulty being funded by NASA. By contrast, the NASA that achieved the great accomplishments of the past had a vision that sought to expand the frontiers in human and robotic space exploration, as well as in basic science and aeronautical research. The agency pursued this vision by encouraging and benefiting from strong international cooperation.

If we were correct in our earlier paper to assert that the space program and NASA were at a critical juncture in 2005, in 2009 the future of the U.S. space program is very much in doubt. The narrow vision of the Bush administration in launching VSE and its subsequent failure to fund the effort adequately have led to serious questioning of the nation's commitment to space and, consequently, to a steady erosion of NASA and the aerospace industry that supports its missions.

NASA has been trapped by expectations it could not meet and promises not kept. Morale at NASA is at a low point, many of the agency's most experienced workers are retiring, and NASA, as well as U.S. aerospace companies, faces dire manpower challenges. President Barack Obama's early decisions regarding NASA will determine whether the United States continues to lead in space or cedes that position to other nations.

In the following sections, we again address the four serious barriers discussed in our 2005 paper. In our view these barriers need to be overcome if the United States is to realize the enormous potential of space science and exploration. Each issue is examined in light of the events of the last four years that have made the challenge more difficult and the need for change more urgent.

In our 2005 paper, we noted that the four barriers to progress in the U.S. space program need not—indeed should not—remain obstacles to future U.S. efforts in space commerce, science and technology, and human exploration of space. However, overcoming these barriers has been made more difficult by the lack of progress during the past four years. There is an urgent need to develop strategies to surmount these barriers if the nation's civil space program is to move forward.

THE FIRST BARRIER: THE IMPACT OF EXPORT CONTROLS ON SPACE COMMERCE

The U.S. policy on export controls in 2009 is basically the same policy that existed in 2005, and it is deeply flawed. The policy, known as ITAR (for U.S. International Traffic in Arms Regulations), governs all space-related matters and requires State Department licensing through a process that is both cumbersome and ambiguous. This bureaucracy also confounds U.S. efforts to conduct space research and operations in cooperation with international partners. Although the problems have significantly worsened since our 2005 paper, recognition of the magnitude of the problem is more widespread today than it was four years ago.

In 2005 we emphasized that the success of the U.S. space science and exploration programs is closely related to the success of the commercial space industry. We noted that revision of ITAR was essential for the United States to improve its competitiveness in space commerce, particularly in the satellite industry.

Since then, European aerospace companies have continued to encounter problems with U.S. trade restrictions. In response, they are choosing to avoid dealing with U.S. export controls by not using American-made parts, by becoming "ITAR-free"—meaning that their products are not subject to ITAR's numerous restrictions and the U.S. government's licensing requirements. Indeed, non-U.S. aerospace companies are advertising "ITAR-free" as a major selling point.

The European Aeronautic Defense and Space Company (EADS) and other European companies have been working to develop components that can replace comparable U.S.-made parts. EADS has developed a satellite motor that is completely ITAR-free and therefore not subject to U.S. export license restrictions, allowing competitive access to worldwide customers. France's Alcatel Space has had a company policy since 2002 to build ITAR-free communications satellites in order to avoid U.S. control over sales. On April 12, 2005, Alcatel launched its first ITAR-free satellite on a Chinese rocket. The company also received two major satellite contracts from China in 2005. Marotta, a British maker of spacecraft propulsion and propellant management equipment, advertises that its products "are European and hold ITAR-free status." And when Surrey Satellite Technology, another British firm, discusses its satellite propulsion systems, they make clear that their systems are "completely ITAR-free."[3]

China has also been successful in pursuing space technology on its own. A U.S. policy that bars China from launching satellites with U.S. components had left China seeking customers from second-tier operators in Asia, Africa, and South America. Recently, however, China has, in addition to its contracts with Alcatel, secured a contract to launch European-based Eutelsat Communications' five-ton satellite. Made without any U.S. components, the Eutelsat satellite is scheduled for launch by China's Long March rocket in 2010. China's launch bid, estimated to be as much as 40 percent below Western competitors, gives it a cost advantage. Other potential launch customers for China are France's Thales Group and Italy's Finmeccanica, which build satellites without U.S. components. China now has a solid track record, with fifteen commercial satellite launches since 2002, the most recent being a communications satellite for Venezuela in October 2008. China has scheduled fifteen more commercial satellites to be sent into orbit in 2009.

A 2007 Air Force Research Laboratory (AFRL)/Department of Commerce (DOC) report highlighted these and other problems being experienced around the world by the U.S. aerospace industry. The report, *Defense Industrial Base Assessment: U.S. Space Industry*, showed that complying with U.S. export control regulations carries a high price tag for U.S. companies and harms their global competitiveness. According to the report, export control compliance costs in the United States averaged $49 million per year industry-

3. Benjamin Sutherland, "Why America Is Lost in Space," *Newsweek*, January 31, 2009.

wide. Compliance costs grew 37 percent during the 2003–2006 period, with the burden of compliance significantly higher for smaller companies.[4]

The report goes on to state that smaller companies feel that ITAR restrictions and limits are a major impediment to their ability to respond to proposal requests and subsequently sell products in foreign markets. Some smaller companies are starting to leave the space industry because of a sustained absence of profitability and a refusal of some foreign companies to deal with ITAR licensing issues. As a percent of foreign sales, the cost burden on smaller companies is nearly eight times that of major firms. These compliance costs include insurance costs, consulting services, compliance-training costs, and Defense Technology Security Administration monitoring costs. For companies that are operating on tight budgets, these accumulating costs can be devastating.

According to the AFRL/DOC report, average net margins are thin and below average for the smaller suppliers, around 5 percent, compared to 9 percent in the high-technology manufacturing sectors in the general economy. A direct correlation exists between export policy, the cost of compliance, and the financial health of the smaller suppliers. For entrepreneurial companies, the net margins (if they exist) are even lower because of the cost of compliance. Entrepreneurial companies have had to restrict discussions with several foreign investors because the companies could not provide the information to perform a due diligence, and this has impacted the availability of investment capital.

This exodus has significant implications for the U.S. industrial base. An Aerospace Corporation analysis published in 2007 expressed concern about the U.S. space supplier base, where in certain critical areas, there is only one domestic supplier left or one financially weak supplier.[5]

A 2007 white paper published by the Space Foundation in Colorado Springs, Colorado, noted that an overly restrictive export control regime, such as ITAR, results in an enfeebled and uncompetitive domestic space industry and can ultimately do as much damage to national security as a lax regulatory system. The foundation expressed concern that the United States is effectively ceding the dominant position in space that it has enjoyed for some time by allowing the expertise of the U.S. space industry to deteriorate. At the same time, the United States' stringent export policy has essentially allowed global competitors to catch up in the global aerospace marketplace and develop capabilities that, in many instances, are similar to those developed in the United States. In Europe, as demonstrated by EADS and Alcatel, U.S. com-

4. Air Force Research Laboratory and the U.S. Department of Commerce, *Defense Industrial Base Assessment: U.S. Space Industry: Final Report* (Washington, D.C.: Department of Commerce, 2007), http://www.bis.doc.gov/defenseindustrialbaseprograms/osies/defmarketresearchrpts/exportcontrolfinalreport08-31-07master___3---bis-net-link-version---101707-receipt-from-afrl.pdf.

5. Jared L. Fortune and Joshua A. Merrill, *Identifying Space Industrial Base Issues* (El Segundo, Calif.: The Aerospace Corporation, 2007), from the AIAA Space 2007 Conference and Exposition, September 18–20, 2007, in Long Beach, California.

ponents and technology are slowly but surely being designed out of systems from satellites to rocket motors.[6]

The present U.S. export controls are also negatively impacting scientific research. The Space Studies Board of the National Research Council (NRC) of the National Academies noted this issue in a report summarizing a September 2007 workshop that included participants from the space research, export control, and policy communities to discuss the application of ITAR to space science.[7] Their report made note of the conflict related to the present export control regulations and scientific research.

Scientific research encourages and thrives on open and free discussions and the interchange of ideas and approaches. Solutions to the environmental problems facing today's world also require international cooperative research. But the current export rules greatly constrain or inhibit such interactions. Much of the university research—basic research—leading to these solutions is government-sponsored and falls under ITAR jurisdiction. ITAR licensing is also required when students or researchers from other countries participate in research. Obtaining ITAR approval places an added burden on researchers and creates uncertainty as to when and if approval will be forthcoming. Additionally, other nations are reluctant to subject themselves to restrictions created by U.S. law and regulations. As a result, the report said, foreign researchers view cooperative research with the United States as less and less desirable.

The current export control laws also raise diplomatic and military concerns. Gordon England, U.S. Deputy Secretary of Defense under President Bush, contends that technology exports should be encouraged because

> in this world of coalition warfare and building partnership capacity, it's essential for us and our friends and allies to have greater interoperability . . . even with vastly different levels of investment. At every level of military activity, from discussions of interoperable hardware designs to battlefield support, the unintended consequences of ITAR can affect the ability of troops and their support personnel to carry out vital tasks.[8]

The same is true of cooperative endeavors in human space exploration where a complete understanding, technically and operationally, of the spacecraft and its systems and the overall mission is critical. Looking back, had ITAR requirements been in place during the planning and operation of the space shuttle and ISS, with their multination crews and control centers, the result could have led to life-threatening situations. Indeed, substantive international cooperation probably would not have been possible.

6. *Space Foundation, ITAR and the U.S. Space Industry* (Colorado Springs: Space Foundation, 2007), http://www.spacefoundation.org/docs/SpaceFoundation_ITAR.pdf.

7. National Research Council, *Space Science and the International Traffic in Arms Regulations: Summary of a Workshop* (Washington, D.C.: National Academies Press, 2008).

8. "ITAR and the U.S. Space Industry," *Milsat Magazine*, November 2008.

If placing space activities under ITAR yielded national security gains, then perhaps all the negative impacts on commerce and science, even military capability, would be worthwhile. But that is not the case. The current policy is simply the result of a "political football" being tossed around by policy-makers who assert that unfriendly nations will steal U.S. technology if the United States does not "lock it all down." However, much of that technology is available for purchase in other parts of the world, and U.S. policies are encouraging countries to develop components and systems that are comparable or superior to U.S. technology, for their own use and for the world market and in lieu of using U.S. components and systems. The Obama administration needs to place a high priority on changing this policy and doing so quickly.

Further compounding the damage done to U.S. industry, export controls and visa restrictions are preventing skilled scientists and engineers from joining the U.S. workforce. Bill Gates, chairman of Microsoft Corporation, has testified to Congress that

> the United States is driving away the world's best engineers and computer scientists by limiting H-1B visas and other immigrant worker programs. More than half of the students in computer science programs at top U.S. universities are from other countries, but a limit on H-1Bs means many of those students can't stay in the United States after they graduate. . . . The fact is, other countries' smartest people want to come here, and that's a huge advantage to us and in a sense, we're turning them away. . . . I believe this country stands at a crossroads. . . . Economic progress depends more than ever on innovation. If we do not implement policies like those I have outlined today, the center of progress will shift to other nations that are more committed to the pursuit of technical excellence.[9]

Even though the need for more engineers and scientists is clear, companies are starting to phase out the hiring of foreign nationals because of the stringent U.S. export control policy.[10] Hiring a foreign national requires an export license, a technology control plan, special training in export control compliance, facility modifications, computer network architecture modifications, and escorting and monitoring the employee. To ensure that it is innovative and competitive, U.S. industry needs to take advantage of the capabilities provided by foreign scientists and engineers. But to do so requires that U.S. export control rules and immigration policies be modified.

Retired U.S. Air Force Col. David Garner, former chief of the Defense Threat Reduction Agency and one of the architects of ITAR restricting the export of U.S. satellites and components, now says the rules need a thorough

9. House Committee on Science and Technology, Competitiveness and Innovation on the Committee's 50th Anniversary with Bill Gates, Chairman of Microsoft, 110th Cong., 2nd sess., March 12, 2008.

10. *Aviation Week and Space Technology*, February 4, 2007.

overhaul because they are damaging U.S. industry with no corresponding benefit to U.S. national security. Garner, speaking at the Satellite 2007 industry conference, said those who helped update the ITAR regulations had no intention of placing almost all satellite systems and components on the State Department-controlled U.S. Munitions List of material to be considered equivalent to arms for export purposes. Garner said the ITAR rules today constitute a minefield for companies seeking licenses to deal with non-U.S. entities to export satellites or related components.[11] Many believe that a clean-slate approach is needed to fix the fundamental disconnect between ITAR as it is being applied to space science research and the needs of the U.S. space science community as it endeavors to maintain world leadership. In short, the rules need to be changed.

Controlling critical space technology exports that would put the nation at risk is indisputably important. But equally important is to be competitive on the world market and to encourage cooperative scientific research when such commerce and research does not compromise critical technology. An export control regime and regulatory environment that protects critical military technologies and technical expertise while still allowing commerce and international scientific partnerships to flourish and the U.S. space industry to prosper and grow should be possible to implement. The ISS is an example of a cooperative space exploration program that benefits all partners.

The January 2009 NRC report *Beyond 'Fortress America': National Security Controls on Science and Technology in a Globalized World* best summarizes the arguments for why concerns about security require a complete revision of the nation's export control regulations. The report states, "As currently structured, many of these controls undermine our national and homeland security and stifle American engagement in the global economy, and in science and technology." Written by the Committee on Science, Security, and Prosperity of the NRC and co-chaired by Brent Scowcroft, president of the Scowcroft Group, and John Hennessey, president of Stanford University, the report calls on the new administration to revise export control policies promptly, by issuing an executive order that affirms "a strong presumption for openness." The report goes on to say, "Economic competitiveness needs to be factored into export control decisions, and controls need to be reviewed annually and rescinded when they can no longer justified." The panel concluded that the perpetuation of existing policies would be "a self-destructive strategy for obsolescence and declining economic competitiveness."[12]

11. Retired U.S. Air Force Col. David Garner, comments made during "The ITAR and COMSATs: Where Are We Today, and Where Might We Go," panel session of the Satellite 2007 conference, Washington, D.C., February 21, 2007.

12. National Research Council, *Beyond 'Fortress America': National Security Controls on Science and Technology in a Globalized World* (Washington, D.C.: National Academies Press, 2009).

THE SECOND BARRIER: THE PROJECTED SHORTFALL IN THE U.S. SCIENCE AND ENGINEERING WORKFORCE

In our 2005 paper, we cited the projected shortfall in the science and engineering workforce in the United States as the second barrier adversely affecting the outlook for the U.S. space program. In 2006–2007, U.S. universities awarded 73,315 bachelor's degrees in engineering, down 1.2 percent from the previous year, and 36,983 master's degrees and 9,065 doctoral degrees. The total number of master's degrees decreased for the second consecutive year, while the number of doctoral degrees increased substantially. Although most of the bachelor's degrees went to Americans, 40.4 percent of the master's degrees and 53.1 percent of the doctoral degrees were earned by students from other nations.[13] These students, in growing numbers, are returning to their homelands in part because of the strict U.S. work permit rules. The number of engineers being produced by other nations is also increasing—particularly in China and India, where new engineering graduates already outnumber those in the United States.

In our earlier paper, we also noted the problem of the aging science and engineering workforce and worries that this demographic shift will leave the United States with an insufficient pool of skilled and experienced scientists and engineers. Approximately 58 percent of the aerospace workforce is over age 50. In 2008, approximately 27 percent of employed engineers became eligible for retirement, and during the next decade the number of employees with science and engineering degrees reaching traditional retirement age will triple.[14] The children of this generation of workers have not chosen careers in science and engineering in the same numbers as their parents. The consolidations that occurred in the aerospace industry in the 1990s also led to layoffs that left the industry with a shortage of middle-age talent in the 30- to 40-year-old range. This age group represents those individuals having both the theoretical and practical knowledge to become program managers, both in industry and in the federal government in the next six to ten years. This shortage of talent could result in these senior positions being filled by younger, less-experienced workers.[15]

The U.S. Bureau of Labor Statistics has projected that the number of engineering positions will increase by 160,000 between 2006 and 2016,[16] an 11 percent increase that does not include the replacement of many retiring engi-

13. American Society for Engineering Education (ASEE), *ASEE Profiles of Engineering and Engineering Technology Colleges* (Washington, D.C.: ASEE, 2007).

14. Aerospace Industries Association (AIA), *Launching the 21st Century American Aerospace Workforce* (Arlington, Va.: AIA, 2008), http://www.aia-aerospace.org/assets/report_workforce_1208.pdf.

15. Joseph C. Anselmo, "Baby Boomers Retirements Could Trigger R&D Crisis," *Aviation Week and Space Technology*, February 4, 2007.

16. Bureau of Labor Statistics (BLS), Occupational Outlook Handbook, 2008–09 edition (2008), http://www.bls.gov/OCO/.

neers. Lockheed Martin alone has indicated it will need 140,000 engineers over the next ten years just to replace retiring engineers. Yet, despite a growing demand for their skills, the number of engineers graduating from U.S. colleges is decreasing. According to the American Society for Engineering Education's 2007 survey, undergraduate engineering degrees declined in 2007 for the first time since the 1990s, ending seven years of growth. The drop was small, 1.2 percent from the previous year.[17] Engineering bachelor's degrees, however, recovered in 2008 based upon the 2008 survey data.[18]

The trend may not, however, show continued growth for several years, as undergraduate engineering enrollment dropped in 2004 and 2005. The need for continued growth in the number of engineering graduates comes at a time of increasing technological competition from Asia and mounting domestic concerns about the growing need for carbon-free energy, protection of the environment, and the nation's decaying infrastructure, to name only a few of the challenges that will require engineering solutions. The 2007 survey showed engineering master's degrees with an even sharper drop than bachelor's degrees in 2007, slipping 8.8 percent since the 2005 survey.[19] In 2008 master's degrees recovered nicely from their previous two year' decline, posting a 5.4 percent increase in 2008. The 38,986 degrees conferred were almost an exact match of the total for 2006. At the master's level, degrees to foreign nationals reached 41.7 percent. This is a 3 percent increase from last year's mark, which was a ten-year low. The number of engineering Ph.D.s, by contrast, had been growing an average of 11 percent per year since 2004. The 2008 survey, however, showed doctoral degrees remained virtually unchanged from the 2007 survey. A substantial number of these Ph.D.s are being earned by foreign nationas. But the 2008 survey showed the share of doctoral degrees awarded to foreign nationals declined significantly for the first time in nine years. Having risen from 45.6 percent in 1999 to 61.6 percent in 2007, this year's 58.3 percentage marks a clear change.

Considering the number of engineering graduates being produced by U.S. universities and the significant numbers of foreign nationals within that number, responding to the vacancies created by industry retirements will be a significant challenge. Looking to the future, the increasing technological competition from Asia and mounting domestic concerns about the growing need for carbon-free energy, protection of the environment, and the nation's decaying infrastructure, to name only a few of the challenges that will require engineering solutions, all create the need to graduate more scientists and engineers from U.S. universities. The need for continued growth in the number of engineering and science graduates will require attracting more young stu-

17. *ASEE Profiles of Engineering and Engineering Technology Colleges*, 2007.

18. American Society for Engineering Education (ASEE), *ASEE Profiles of Engineering and Engineering Technology Colleges* (Washington, D.C.: ASEE, 2008).

19. *ASEE Profiles of Engineering and Engineering Technology Colleges*, 2007.

dents to pursue careers in these fields. This will be difficult to do at a time when, along with the other problems that exist in the nation's educational system, U.S. students are showing an alarmingly low interest and ability in science and math. A report released in March 2008 by the National Mathematics Advisory Panel found that the nation's math teaching system is "broken and must be fixed" if the United States wants to maintain its competitive edge. The panel called for a comprehensive, systemic effort to strengthen math education, including improving teacher training and professional development.

The October 2004 NRC report *Rising above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* probably best defines the problem facing the nation.[20] Identifying a number of concerns with the nation's educational system, the analysis points out that less than one-third of U.S. students in the fourth and eighth grades performed at or above the "proficient" level in mathematics—"proficiency" being defined as the ability to exhibit competence with challenging subject matter. About one-third of the fourth graders and one-fifth of the eighth graders lacked the competence to perform basic mathematical computations. The adequacy of the teaching was identified as another area of concern. In 1999, 68 percent of U.S. eighth-grade students received instruction from a mathematics teacher who did not hold a degree or certification in mathematics. In 2000, 93 percent of students in grades 5–9 were taught physical science by a teacher lacking a major or certification in the physical sciences (chemistry, geology, general science, or physics).

The report goes on to comment on higher education in the United States, noting that the number of U.S. physics bachelor's degrees awarded in 1956, the last graduating class before *Sputnik,* was almost double that in 2004. The report also presents comparative data from around the world. In South Korea, 38 percent of all undergraduates receive their degrees in the natural sciences or engineering. In France, the figure is 47 percent; in China, 50 percent; and in Singapore, 67 percent. The comparative figure for the United States is 15 percent.

The report also cites the percentages of U.S. degrees received by students from abroad: for example, 34 percent of the doctoral degrees in natural sciences (including the physical, biological, earth, ocean, and atmospheric sciences) and 56 percent of the engineering doctoral degrees in the United States are awarded to foreign nationals. In the U.S. science and technology workforce in 2000, 38 percent of the workers with doctoral degrees were foreign nationals.

Estimates vary as to the number of engineers, computer scientists, and information-technology students worldwide who obtain two-, three-, or four-year degrees. *Rising above the Gathering Storm* notes that in 2004, China graduated about 350,000 engineers, computer scientists, and information technologists with four-year degrees; the United States graduated about 140,000. China also graduated about 290,000 with three-year degrees in

20. National Research Council, *Rising above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* (Washington, D.C.: National Academies Press, 2007).

these same fields, while the United States graduated about 85,000 with two- or three-year degrees. From 2002 to 2005, both China and India doubled their production of three- and four-year degrees in these fields, while the U.S. production of engineers was stagnant and the rate of production of computer scientists and information technologists doubled. The numbers are large even if you were to cut them in half.[21] Students throughout much of the world see careers in science and engineering as the path to a better future. By contrast, about one-third of U.S. students intending to major in science and engineering switch majors after their first year.

For the engineering and science students who do graduate from U.S. universities, aerospace engineering will likely not be their final destination. According to a study commissioned in 2007 by *Aviation Week and Space Technology,* today's engineering graduates rank the aerospace and defense fields low—if not last—on their list of industries providing desirable employment, far behind high technology and professional services. Just 7 percent of students at fifteen top engineering schools interviewed for the study expected they would pursue a career in aerospace.[22] The solutions to today's pressing environmental and climate change issues and the need for the United States to pursue alternative energy sources will also create demands for more new young innovative scientists and engineers. Considering these needs and the impending retirements serves to heighten the competition for the young graduates and will contribute to a larger shortfall in the aerospace science and engineering workforce.

The National Science Board stated the overall dilemma in their *Companion to Science and Engineering Indicators 2004*:

> If the trends identified in *Indicators 2004* continue undeterred, three things will happen. The number of jobs in the U.S. economy that require science and engineering training will grow; the number of U.S. citizens prepared for those jobs will, at best, be level; and the availability of people from other countries who have science and engineering training will decline, either because of limits to entry imposed by U.S. national security restrictions or because of intense global competition for people with these skills. The United States has always depended on the inventiveness of its people in order to compete in the world marketplace. Now, preparation of the [science and engineering] workforce is essential for national competitiveness.[23]

The workforce situation is critical to the future well-being of the United States and, much like the present economic crisis, demands immediate attention. Even if action is taken today, significant time will be needed to change

21. Anselmo, "Baby Boomers Retirements Could Trigger R&D Crisis."

22. Ibid.

23. National Science Board, "An Emerging and Critical Problem of the Science and Engineering Labor Force: A Companion to Science and Engineering Indicators 2004," NSB 04-07, January 2004.

the present trends—an estimated ten to twenty years according to the National Science Board.[24]

Rising above the Gathering Storm includes specific recommendations aimed at improving the teaching of science, technology, engineering, and mathematics and attracting more U.S. boys and girls to careers in science and engineering, including competitive merit-based scholarships for bachelor of science degrees for 10,000 new teachers, summer training programs for 250,000 teachers, a new master's degree program, Advanced Placement and International Baccalaureate (AP/IB) training, and new AP/IB and pre-AP/IB science and mathematics courses.[25] All of these recommendations are based on evidence acquired through many years of research on the effectiveness of such programs.

In the past, foreign students have come to the United States in large numbers to receive a quality higher education and, following graduation, have found faculty positions or employment with American companies in need of engineers and scientists. This has helped to alleviate the shortfall in the numbers of engineering and science students who are U.S. citizens. Immigration procedures implemented since September 11, 2001, however, have discouraged foreign students from applying to U.S. schools and have made it difficult for those foreign students who do graduate from U.S. universities to obtain employment in the United States. Overly restrictive export control regulations exacerbate the situation.

In his 2008 testimony to the House of Representatives Committee on Science and Technology, Bill Gates said of the contributions of these foreign-born scientists and engineers: "U.S. innovation has always been based in part on foreign-born scientists and researchers. The fact that other countries' smartest people have wanted to come here has been a huge advantage to us, and in a sense, we're kind of throwing that away." Gates went on to say, "I want to emphasize that the shortage of scientists and engineers is so acute that we must do both: reform our education system and reform our immigration policies. This is not an either-or proposition. If we do not do both, U.S. companies simply will not have the talent they need to innovate and compete."[26]

Specifically, Gates wants to improve the quality of education in all schools, especially in science and math; attract many more U.S. citizens to careers in science and engineering; and lower barriers to allow talented young people to come to the United States to study and work.

Rising above the Gathering Storm proposes a number of specific immigration reforms designed to attract talent from overseas, including an automatic one-year visa extension for international students who receive doctorates or the equivalent in science, technology, engineering, mathematics, or other

24. Ibid.

25. National Research Council, *Rising above the Gathering Storm*.

26. House Committee, Competitiveness and Innovation.

fields of national need at U.S. universities, to allow them time to seek employment. The report recommends that if U.S.-based employers offer these students jobs and if they pass a security screening test they should be provided automatic work permits and expedited residence status. If the students are unable to obtain employment within the one-year period, their visas would expire. The report also recommends the creation of a new skills-based, preferential immigration option for individuals with a doctorate-level education and science and engineering skills that would give them a priority in obtaining U.S. citizenship. In the interim, the report recommends that the number of H-1B visas be increased by 10,000 and that the additional visas be made available to industry to allow the hiring of science and engineering applicants with doctorates from U.S. universities.

The NRC report also proposes the revision of the current system of "deemed exports" or transfers of controlled information and technical data to non-citizens on U.S. soil. This information sharing is regulated as though an export controlled commodity were being sent to the foreign national's country of residence or citizenship and thus requires the "deemed" exporter—whether a university, a private contractor, or an independent research institution—to obtain a license.

The proposed new system would provide international students and researchers engaged in fundamental research in the United States access to information and research equipment in U.S. industrial, academic, and national laboratories that is comparable to access provided to U.S. citizens and permanent residents engaged in similar research. Foreign students would not have access to information and facilities restricted under national-security regulations. The report recommends that all technology items (information and equipment) that are available for purchase on the overseas open market or that have manuals that are available in the public domain (libraries, the Internet, or from manufacturers) be removed from the deemed-exports technology list to facilitate the fundamental research work of international students and scholars.[27]

The NRC's 2009 report *Beyond 'Fortress America'* also assails the current U.S. visa policy for inhibiting collaboration with foreign experts and the difficulties of absorbing foreign students into the workforce in the United States:

> Current law has the perverse effect of permitting foreign students to enter the United States only if they can prove to a consular officer's satisfaction that they will take what they learn home with them . . . anyone who admits that he or she might want to stay in the United States and contribute to this country's technological competitiveness must—by law—be denied entry.[28]

27. National Research Council, *Rising above the Gathering Storm.*

28. National Research Council, *Beyond 'Fortress America.'*

The arguments and data in the NRC reports, bolstered by Bill Gates's testimony to Congress, offer sensible recommendations for actions that, if taken, could reverse the trends and, in time, help to provide a solution to the projected shortfall in the U.S. science and engineering workforce. Failing to implement these recommendations not only will damage the ability of the United States to maintain a leadership role in space, but also will affect the nation's overall ability to maintain a position of leadership in the world. Making real progress will not be easy. But the stakes are high and time is short.

Today, the concerns expressed in the reports of the NRC and National Science Board remain. In 2007, Congress passed the America COMPETES Act (Public Law 110-69), and President Bush signed it into law. The act authorized increases in the nation's investment in Science, Technology, Engineering, and Mathematics (STEM) education programs at several agencies, as well as science and engineering research at the National Science Foundation (NSF), the National Institute of Standards and Technology (NIST) laboratories, and the Department of Energy (DOE) Office of Science. In the deliberations over the fiscal year (FY) 2008 budget, Congress was prepared to include substantial increases in the appropriations for research and education, but disagreements with the Bush White House over the bottom-line figure for discretionary spending resulted in a number of last-minute cuts, including all of the increases in research funding for these agencies.

However, with the election of President Obama and a Congress that is more in line with his agenda, reasons for optimism have increased. First, during his presidential campaign, then-Senator Obama made clear that science and education would be high priorities in his administration. Second, when the American Recovery and Reinvestment Act of 2009 (Public Law 111-5; the "stimulus bill") was put together, it included large increases for the NSF, DOE's Office of Science, NIST, the National Institutes of Health, the Department of Education, and others. This funding will accelerate research and STEM activities as well as give states the resources to help retain K-12 teachers and will, in general, improve K-12 teaching and learning across the nation. While the "stimulus" funding is one-time money, the president's budget requests for FY2009 and FY2010 also contain substantial increases for research and STEM education. The budget developments are highly encouraging, but pitfalls dot the landscape. If the agencies do not manage the stimulus funding well, Congress could push back on the president's FY2010 budget request, leading to several years of disappointing budgets for federal research and STEM education.

Most Americans might not see how increasing research funding will improve STEM education, other than producing more Ph.D.s in science and engineering. The nation's universities, recipients of much of this funding, need to accept a larger share of responsibility for the full education spectrum from K-12 onward, especially the need to improve the quality of teacher education in science and mathematics.

Making sustainable progress in addressing the large systemic problems that challenge the nation's future will require leadership at the top. On April 27, 2009, President Obama addressed the annual meeting of the National Academy of Sciences. The president noted:

> We led the world in educational attainment, and as a consequence we led the world in economic growth. The G.I. Bill, for example, helped send a generation to college. But in this new economy, we've come to trail other nations in graduation rates, in educational achievement, and in the production of scientists and engineers.
>
> That's why my administration has set a goal that will greatly enhance our ability to compete for the high-wage, high-tech jobs of the future—and to foster the next generation of scientists and engineers. In the next decade—by 2020—America will once again have the highest proportion of college graduates in the world. That is a goal that we are going to set. And we've provided tax credits and grants to make a college education more affordable.[29]

The president's message makes clear that he is serious about progressive change for America. His goal is attainable, but the whole nation will need to work together to make it a reality.

THE THIRD BARRIER: INADEQUATE PLANNING FOR THE FUTURE OF NASA AND THE U.S. CIVILIAN SPACE PROGRAM

From John Glenn's Mercury flight to the Apollo moon landings to spectacular planetary, astronomical, and Earth-observation missions—culminating in the ISS—the United States has maintained a proud record of leadership in space with a balanced program of manned and unmanned orbital and exploration missions and science and engineering research. The space shuttle program is the longest running, most successful fleet of manned space vehicles ever made. The ISS, upon completion, will represent the largest international cooperative technological project in history.

The successful Viking spacecraft landings on Mars provided the most complete view ever of the planet. Exploration of the "red planet" has continued with *Mars Pathfinder* and its Sojourner rover and, more recently, with the highly successful Mars exploration rovers, Spirit and Opportunity. NASA's Earth Observation System (EOS) missions have contributed not only to increased scientific understanding of Earth's surface and atmosphere, but have been critically important to weather prediction, hurricane tracking, and responding to natural disasters, among many other societal applications.

29. Barack Obama, "Remarks by the President at the National Academy of Sciences Annual Meeting," press release, April 27, 2009, http://www.whitehouse.gov/the_press_office/Remarks-by-the-President-at-the-National-Academy-of-Sciences-Annual-Meeting/.

NASA's aeronautics research and technology program has also produced significant advancements in aeronautical design, including the low-drag cowl for radial engines and the "Coke bottle" to reduce transonic drag rise. More recent aeronautics advancements—including multi-axis thrust vectoring exhaust nozzles integrated with aircraft flight-control systems; fly-by-wire flight control technologies; high-strength, high-stiffness fiber composite structures; and tilt-wing rotorcraft technology—have been achieved in partnership with NASA's research and technology programs. Aeronautical capabilities are important to the U.S. economy. Today the aeronautics industry is faced with the challenge of an increasingly competitive world and a declining share of the world aerospace market.

The agency that achieved so many incredible advances during its first fifty years did so with a balanced program of activities in science, engineering, and exploration, utilizing both human and robotic spacecraft and cutting-edge aeronautical research, all built on a sound foundation of research and technological innovation.

In 2004, a year before the publication of our earlier paper, President Bush chose to establish a new course for NASA and the civil space program. He announced VSE, a bold plan to complete the space station and phase out the space shuttle by 2010. Under VSE, a replacement for the space shuttle, the Crew Exploration Vehicle, was to be built and tested by 2008, and the first manned mission flown no later than 2014. Human beings would return to the moon by 2020 and prepare for missions to Mars. Bush's VSE was to be led by the United States.

In our 2005 paper we spoke of the need for an American vision in space that would be challenging but realistic, and we expressed the view that, although returning to the moon and going to Mars are worthy long-term goals, they should not be the only important, or even the most important, goals of the space program. We argued that science, including the highly successful missions to the planets, the dramatic robotic exploration of the surface of Mars, the development and deployment of Earth-observing satellites, as well as many missions still in the planning stages, should be among the highest priorities for NASA. New scientific knowledge and the development and application of revolutionary technologies to support scientific and exploration missions have been the tangible products of the nation's investment in space and the key to NASA's accomplishments and well-deserved reputation for excellence and creativity throughout the world. We expressed the view that a commitment to not diminishing the priority of science in any new program was vital to NASA's future, and we argued that the Bush administration should make clear its commitment to science at a time when NASA budgets were being reallocated to show progress on the president's vision of returning human beings to the moon.

A great deal has changed since 2005. A rapidly changing social and political environment, a series of decisions that affect the nature of the challenges to the space program and create new ones, and four years of inattention to many of these issues have resulted in the bar being raised even higher. Perhaps the greatest change is in NASA itself. NASA is becoming an agency all-too-focused on a single mission. If your activity is not about returning people to the moon and going to Mars, you will have difficulty getting your activity funded.

Important research that was previously being done by NASA has been terminated. The traditional NASA research centers Langley, Glenn (Lewis), Ames, and Dryden have become program management centers, and much of the nation's research that had been supported by NASA is not being done.[30] The first *A* in NASA has always stood for "aeronautics," and NASA and its predecessor, the National Advisory Committee for Aeronautics, had a rich heritage of aeronautical research going back almost a hundred years. The nation's civil space and aeronautics program, traditionally a balanced program, is becoming more and more a program that places its emphasis on just one activity.

The ISS, involving close partnerships with Russia and thirteen other nations, has been a great accomplishment, the largest international cooperative technological project in history. In 2008, the European and Japanese research modules were installed on the station, and the partners are now in a position to gain a return on their substantial investment. But with the United States ending its support of the space shuttle program, its partners' planned research is in jeopardy, and they will have no access to the new VSE program.

Indeed, the decision to stop flying the space shuttle signaled that the United States no longer had much interest in the ISS, and that after 2010 other nations would be more or less on their own. NASA plans to buy trips to the space station on Russian Soyuz and Progress (cargo) spacecraft, but with relations between the United States and Russia at a low point, Congress has already questioned this arrangement.

If the space program and NASA were at a critical juncture in 2005, today the future of the U.S. space program is very much in doubt. Despite continued great accomplishments, the bold pronouncements by the Bush administration in launching VSE, followed by inadequate funding, have led to serious questioning of the nation's commitment to space and, consequently, to a steady erosion of NASA and the aerospace industry that supports its missions.

President Bush presented his vision, but, as the saying goes, vision without funding is a hallucination. No cost estimates were presented for returning human beings to the moon or for sending them to Mars. The president committed to adding $1 billion to the NASA budget each year for five years, with another $11 billion to come from reallocations—amounts far short of what would actually be required to build a new space vehicle and prepare for a re-

30. NASA administrator Michael Griffin said in an email in 2006, "We are not, any longer, a technology agency to any significant extent. Wishing otherwise is nice, but irrelevant"; "Is NASA Glenn in This Fight?" *Cleveland Plain Dealer*, April 16, 2006.

turn to the moon. The cost of the Apollo program was approximately $135 billion in 2004 dollars, but the president did not request even the small increases he had promised, and NASA has had to reduce other ongoing activities to support the new vision. Former astronaut and U.S. Senator John Glenn of Ohio has called the Bush VSE program "one of the biggest unfunded mandates that we have had in all of government history."[31]

In our 2005 paper, we stressed that it was vital to NASA's future that the priority of science not be diminished in the new program. As NASA has scraped to find the money to fund the VSE program, science has paid the price with large cuts in NASA's research programs and space-based science missions, including Earth-observation satellites needed for weather and climate change observations. Other equally important activities, such as aeronautical research, have suffered a similar fate. A comprehensive look at President Bush's budget for research and development in FY2009 shows that NASA's budget grew by $497 million, or 2.9 percent, to $17.6 billion, but that the science portfolio was cut by 5.6 percent and aeronautics research by 13 percent.[32] Fortunately, the American Recovery and Reinvestment Act of 2009, passed by Congress and signed into law by President Obama, will provide funds to begin to address some of the cuts in NASA's space-based science and Earth-observation missions.

A prime example of the differing priority given to science by NASA under the Bush administration was the decision not to fly the Alpha Magnetic Spectrometer (AMS). In 1995, Samuel Ting, the Nobel Prize-winning particle physicist, proposed to use the ISS to examine the depths of the universe for antimatter. The experiment would sift cosmic rays—the high-energy particles from the sun, other stars, and even galaxies in outer space—with unprecedented sensitivity and precision, opening a new window on the universe. By looking for the opposites of ordinary matter, the experiment would shed light on why the universe appears to be made overwhelmingly of matter—although the laws of physics suggest that matter and antimatter should have been born in equal amounts. The discovery of antimatter from some distant antigalaxy would have great scientific significance. The experiment might also, among other discoveries, detect signals from the mysterious "dark matter" that accounts for 25 percent of the universe.

The experiment is now almost complete after ten years of development at a cost of $1.5 billion; it has been developed by a team of more than 500 scientists from fifty-six institutions representing sixteen countries, including both China and Taiwan. The governments of these countries have all helped to provide the funds for the AMS, which would be among the most expensive international space instruments ever built. The experiment has been reviewed by a blue-ribbon panel of physicists and judged to have the potential to make "fun-

31. Brian Berger, "John Glenn Calls Bush Space Vision an Unfunded Mandate," *Space News*, July 31, 2008, http://www.space.com/news/080731-glenn-bush-space-vision.html.

32. American Association for the Advancement of Science, "Preliminary Analysis of R&D in the FY2009 Budget," February 7, 2008, http://www.aaas.org/spp/rd/prel09p.htm#hi.

damental new discoveries." NASA signed an "implementing arrangement" with the U.S. Department of Energy in 1995, agreeing to fly the AMS experiment on the station to the ISS if the department built it. But as NASA increased its emphasis on implementing the Bush VSE with inadequate budgets, it made the decision that other planned activities that supported VSE would be assigned a higher priority and the AMS would not fly. NASA's cancellation of the AMS must stand as one of the most bizarre scientific policy decisions of the Bush administration. This experiment alone, with its potential to probe the foundations of modern physics, provides a major justification for the U.S. investment in the ISS over and above the value of its life-science research. But even research in the life sciences has fallen under the ax of VSE. The Advisory Committee on the Future of the U.S. Space Program, chaired by Norm Augustine, was established in 1990 to advise the NASA administrator on overall approaches NASA management could use to implement the U.S. space program in the coming decades. In its December 1990 report, the committee determined that "the Space Station is deemed essential as a life science laboratory, for there is no Earth-bound substitute." The committee's report went on to say:

> Fundamental uncertainties remain with respect to the feasibility of long duration human spaceflight, uncertainties that revolve around the effects of solar flares, muscle deterioration due to weightlessness, the loss of calcium in human bone structure and the impact of galactic cosmic radiation. These basic issues need to be resolved before undertaking vast projects by means of long duration operations involving humans in space. We thus arrive at what we believe is the fundamental reason for building a space station, to gain the much needed life science information and experience in long duration space operations. Such information is vital if America is not to abdicate its role in manned space flight.[33]

Nearly twenty years later, the committee's recommendations are still valid. But as NASA redirected its priorities to support VSE, the committee's recommendations appear to have been given little consideration, and the life science program has suffered significant reductions.

Beyond studying the long-term effects of zero gravity on human physiology, NASA historically studied other important life sciences and related technologies that could benefit people living on Earth. These efforts have been terminated as VSE has pushed aside NASA science. A good example is the Bioreactor, a cell culture device developed as part of space medicine research at NASA's Lyndon B. Johnson Space Center. The Bioreactor could potentially allow scientists to better test new treatments for cancer and viruses without risking harm to patients. The rotating-wall Bioreactor mimics the effect

33. Advisory Committee on the Future of the U.S. Space Program, *Report of the Advisory Committee on the Future of the U.S. Space Program* (Washington, D.C.: NASA, 1990), http://history.nasa.gov/augustine/racfup1.htm.

that weightlessness might have on cell cultures by incorporating a rotating cylinder to hold the culture. The rotating vessel does not really cancel gravity but maintains cells in continual free fall similar to that experienced by astronauts in the microgravity of space. With rotation, pressure points on the growing cells are relieved, allowing the device to grow three-dimensional, highly accurate tissues, unlike previous culture experiments that allowed growth in only two dimensions. This ensures that the fluid rotates without shear forces that would destroy the cells. It spins a fluid medium filled with cells. Already being commercialized, the device has been used to grow more than thirty-five cell types, and no cell type yet tested has failed to grow well in the system. In 2005, despite plans well underway to devote a research facility on the ISS to advance this much-needed research, the program was eliminated based on the conclusion it did not support going to the moon or Mars.

We expressed concern in our 2005 paper that Bush's VSE plan would redirect NASA's science programs, placing them at lower priority and making deep cuts in research funding. Science has been fundamental to NASA's success in advancing human understanding of the universe, the solar system, and Earth, and in providing the knowledge and technology that enable human exploration of space. Any truly visionary plan for NASA's future should specify science, including robotic exploration of space and satellite observations of Earth, as one of NASA's principal goals. Otherwise, the unique contributions that NASA can make to astronomy and to planetary, earth, and space science will be lost. America will cede its traditional leadership role in these frontier areas of science to other parts of the world. The last four years, during which science has continued to lose ground in NASA's budget decisions, have proven the validity of those concerns.

Our 2005 paper also raised concerns about ongoing space transportation aspects of NASA's plan for implementing Bush's VSE, including the decision to retire the space shuttle in 2010, presumably after the European ISS module Columbus and the Japanese JEM module are taken to orbit. We suggested that the ISS would not be able to realize its potential without the space shuttle, because the station requires both up-mass and down-mass capability (to take large objects to the station and return obsolete items to Earth) that can be satisfied only with the space shuttle. The proposed space shuttle replacement, the Constellation space vehicle—an Orion crew exploration vehicle that rides to space on a new Ares I rocket—would not have that capability.

Moreover, progress on developing the Constellation space vehicle has been delayed because of significant technical design problems. As a result, the Constellation will not be ready before 2015 and, realistically, probably much later. Even if all of the problems can be solved with considerably more time and money, the capabilities of the new system fall far short of the space shuttle in many ways. The Orion capsule, a larger version of the 1960s Apollo capsule, does not allow for extravehicular activity, cannot stay long in orbit, carries no payload up or back, and must land in water. In the meantime, if the United

States is to continue to play a role in the ISS, its only access will be by purchasing rides on the Russian Soyuz. This creates a good deal of uncertainty about the United States' continued involvement in the ISS and the nation's ability to meet international commitments to its partners.

The hard requirement to retire the space shuttle in 2010 has created another concern. A limited number of approved shuttle missions remain. The artificial retirement wall puts tremendous pressure on the schedule to ensure all the missions are flown in the remaining months. This, in turn, puts enormous pressure on the system and its personnel and could create major safety issues. The situation is further aggravated as the shuttle workforce seeks employment elsewhere because of the impending termination of its positions. What are these talented people, who have devoted their lives to the shuttle, supposed to do after 2010? The plan for retiring the shuttle, if indeed it is to be retired, should not be based on an arbitrary calendar date. Rather, missions should be flown when they are ready to fly.

Because of budget and personnel shortfalls, NASA is unable to provide firm cost estimates for VSE. Meanwhile, tight White House deadlines created by the Bush administration continue to put pressure on both the Ares I and Orion projects. Both projects are likely to continue to experience substantial schedule slips and growth in costs. The best advertised estimate of when the Constellation might fly is 2015; realistically, its first flight could be much later. All the while, science will continue to be held hostage unless a change in direction is made. The present direction—set by VSE and NASA's resulting planning and implementation—has adversely affected NASA's programs for scientific research, including research focused on using space to better understand Earth's environment. The current course has also had a serious negative impact on international programs such as the ISS.

In our previous paper, we acknowledged the success of Russia's space program, including its excellent space technology, skilled workers, considerable experience in orbit, and an admirable safety record. However, we expressed the opinion that it would be a mistake to be completely dependent on any one nation's space program (whether that of Russia or another nation) when human lives are at stake. We stated that the space shuttle should be returned to flight once the safety improvements recommended in the *Columbia* accident report had been made and that the shuttle should continue to fly until a new space vehicle with the necessary up-mass and down-mass capability has been designed, tested, and placed into operation.[34] We also recommended that the long-planned space shuttle upgrades, including those recommended by the Columbia Accident Investigation Board following the 2003 *Columbia* accident, be implemented to improve shuttle safety and reliability. The long-planned space shuttle upgrades were canceled by the Bush administration even though they had successfully passed their qualification tests at great expense and were ready to be installed.

34. Columbia Accident Investigation Board, *Report*, vol. 1–6 (Washington, D.C.: NASA, 2003), http://caib.nasa.gov/news/report/default.html.

All of this says to us that the United States should rethink the national strategy for human spaceflight. The current single-focus approach NASA has adopted in order to implement President Bush's VSE is unsustainable, could lead to the nation losing its capability to fly human beings in space for a considerable period of time, and continues to hold scientific research and aeronautics hostage to inadequate budgets. Moreover, uncertainties in the cost of VSE continue to be large, making planning of any kind unnecessarily difficult. Furthermore, no effort has been made to ascertain the willingness of the American people to pay the large costs of returning human beings to the moon.

We applaud President Obama's recent decision to convene an independent panel that will conduct a comprehensive review of NASA's human spaceflight program. Norman Augustine has been named to chair an independent review of U.S. human spaceflight plans. During the course of the review, the panel will examine ongoing and planned NASA development activities and potential alternatives in order to present options for advancing a safe, innovative, affordable and sustainable human spaceflight program following the space shuttle's retirement. The committee is planning to present its results in time to support an administration decision on the way forward by August 2009.

THE FOURTH BARRIER: A LOSS OF INTERNATIONAL COOPERATION

In our 2005 paper, we expressed our deep concern that other nations, including U.S. partners in the ISS, were not being invited to join the United States as true partners in the early planning stages of future human space-exploration missions. President Bush, in his speech of January 14, 2004, seemed to invite other nations to share the challenges and opportunities of his vision and the new era of discovery.[35] However, NASA leadership subsequently contradicted that promise when then-NASA administrator Sean O'Keefe stated that the new space initiative was "very much going to be a U.S.-led endeavor. That's our intent. And, again, much of what we had been directed and what the president envisions we do is to achieve this set of American, U.S. exploration objectives."[36] O'Keefe's statement left little room for ambiguity about the role of future international cooperation. We stated in our earlier paper that, given the present limited U.S. capability to undertake such a major program as returning human beings to the moon and sending them to Mars, international cooperation clearly would be necessary for these missions. Thus, excluding potential international partners at the outset all but assured that the president's vision could not be fulfilled.

That was 2005, before the federal deficit grew to an expected trillion dollars in 2009, before the country was faced with an economic crisis the likes of

35. Bush, "Remarks by the President."

36. Sean O'Keefe, "Press Conference on the Future Vision for Exploration," Washington, D.C., January 14, 2004, http://www.nasa.gov/pdf/54876main_okeefe_transcript_04012004.pdf.

which had not been seen since the 1930s. Since 2005, the nation has also become more aware of the difficulty of providing energy security and coping with the threats of climate change and the consequent domestic security, foreign policy, and economic challenges. These critical issues will all impact the budget and will necessitate the prioritization of available funding. International cooperation, in today's environment, has become even more of a necessity for human missions to the moon and Mars.

Forming international partnerships does not exclude national objectives; indeed, on balance, it often helps nations meet their objectives. But effective partnerships do require a sharing of vision, objectives, and commitments from the beginning of the enterprise. The United States cannot expect other nations to participate enthusiastically and to provide the necessary staffing, share technologies and skills, and help with funding without that early involvement. Our conversations in 2005 and more recently with scientists, engineers, and policy-makers around the world have confirmed what seemed apparent at the time VSE was announced: the United States during the Bush administration made no effort to bring other nations into the planning process, but expected them to take on the operation of the ISS and to provide assistance for other U.S.-led space efforts if asked. Instead, the Bush administration made the VSE program about national security and, as a result, discouraged any degree of international cooperation on the effort. In our view, America does not have a future in the peaceful uses of space—human space exploration, space science, or commercial space activities—without that degree of international cooperation.

In our 2005 report we noted that the issue most threatening the continuation of U.S. cooperation in space might well be a growing international perception that the United States intends to control space militarily. In 2005 the United States had accelerated its efforts to put in place a questionable missile-defense system. The decision had been made apparently without any international consultation and before adequate research and development had shown the feasibility of such a system. This action suggested that the United States was impatient to signal to the rest of the world that it intends to treat space differently in the future than it has in the past. Many members of Congress who have been advocating for a missile-defense system for several decades heartily endorsed the decision. Powerful industrial interests are also at stake.

Missile defense is only one aspect of U.S. interest in the increased military use of space. The *Report of the Commission to Assess United States National Security Space Management and Organization*, published in 2001, identified the importance of space to national security and outlined a series of recommendations for the future of military space activities. The report proposed, among other things, that the military vigorously pursue capabilities that would enable the president to deploy weapons in space "to deter threats to and, if necessary, defend against attacks on U.S. interests."[37]

37. Commission to Assess United States National Security Space Management and Organization, *Report of the Commission to Assess United States National Security Space Management and Organization* (2001), http://www.fas.org/spp/military/commission/report.htm.

This proposal represented a departure from President Kennedy's vision of 1962, when he vowed, "We shall not see space filled with weapons of mass destruction but with instruments of knowledge and understanding."[38] In our 2005 report we stated that placing offensive weapons in space would be a cause for alarm throughout the world and would create a major obstacle to international cooperation in space. American companies could expect an even more restrictive U.S. export control policy. Such restrictions could further damage commercial space activities and preclude the willingness of other nations to join U.S.-led programs for both human and robotic space science and exploration missions.

The placement of weapons in space would reinforce in the world community the feeling that the United States is increasingly basing its foreign policy on unilateral initiatives. As such, it would severely impact the progress that has been made over the last fifty years toward multilateral international cooperation. The Cold War is over, but the critical national security component of the next generation of spacecraft is being used as the basis for the United States having second-to-none space superiority and going its own way in pursuit of a lunar and Mars program.

In 2007, Joan Johnson-Freese addressed this attitude and its impact in her book, *Space as a Strategic Asset*. "Unfortunately, between fears about U.S. intentions to weaponize space, constraints on American companies' abilities to act as reliable and rational aerospace business partners, and the United States potentially backing out of international commitments like the ISS, the U.S. leadership image has taken a beating."[39] She proposed an alternative approach:

> In the 1960s, leadership was the motivation that took the United States to the moon, as the country wanted to show itself as the winner in a technology-based competition against the Soviet Union. It was a techno-nationalist show of prowess. Today, post–September 11 and equally or more important, with the ongoing war in Iraq, the United States needs to again recognize and embrace the leadership opportunity offered by manned space exploration but this time based on cooperation, not competition. Leading an international inclusive expedition from earth allows the United States to counter its unilateralist militarist image, which has prevailed due to both the Iraq war and U.S. moves toward space weaponization. Such a choice would go a long way toward rebuilding American soft power by positively leading the world on a global endeavor to step into space together for exploration development and applications useful on earth. It is the ultimate positive "big event" strategic communication message of leadership. From the global participants' side, taking part in a grand space program does more than just help countries construct technology and create industries; it builds dreams and generates

38. John F. Kennedy, "Address at Rice University on the Nation's Space Effort," September 12, 1962.

39. Joan Johnson-Freese, *Space as a Strategic Asset* (New York: Columbia University Press, 2007).

pride. Working cooperatively with other countries on a space venture would also alleviate fears about U.S. intentions to monopolize space.[40]

The benefits of international cooperation in space, as opposed to competing militarily in space, are no better exemplified than by U.S. cooperation with Russia, its former Cold War antagonist. The benefit of U.S.-Russian cooperation is summarized in Susan Eisenhower's book, *Partners in Space*. She writes:

> U.S.-Russian cooperation in space since the end of the Cold War has brought significant technological and economic benefits, while strengthening national security. The cooperation achieved an unprecedented degree of interdependence (with Russia's role on the critical path to space station completion) and provided much needed redundancy in the post-Columbia support of space station operations. In bringing Russia into the partnership the United States enhanced national security, as well as international security by strengthening the non-proliferation of rocket technology through the Missile Technology Control Regime (MTCR). It also contributed to the establishment of a strategic partnership, so needed now in the war on terrorism.

Eisenhower goes on to state, "The joint work on the space station brought indispensable experience in building, through cooperation, a large scale international project, which may serve as the stepping stone to the next level of space exploration with potentially even broader international participation. It has also provided a model for other areas of cooperation."[41]

Rose Gottemoeller, a noted expert in Russian studies and President Obama's Assistant Secretary of State for Verification, Compliance, and Implementation, has stated the U.S.-Russian human spaceflight relationship unquestionably should be the model for all U.S. cooperative activities with Russia. Unfortunately, in recent years that has not been the case. Actions initiated as a result of VSE have seriously damaged cooperation on international programs such as the ISS. The United States has had to rely on the Europeans and Japanese—who have made substantial investments in the space station and have finally installed their own research modules on the station—to meet U.S. commitments and continue as partners in the space station enterprise. Otherwise, their planned research would be in jeopardy.

Unless this unfortunate situation is reversed, potential international partners will think twice before joining the United States in future large-scale endeavors. Obama can change the "go it alone" policies of the previous administration by restructuring the exploration program to make it a truly cooperative international effort and ensuring that the ISS, as Susan Eisenhower has predicted, serves as the stepping stone to the next level of space exploration with potentially even broader international participation.

40. Ibid.

41. Susan Eisenhower, *Partners in Space: US-Russian Cooperation after the Cold War* (Washington, D.C.: The Eisenhower Institute, 2004).

However, even with the best intentions of the Obama administration, the cooperation that Joan Johnson-Freese, Susan Eisenhower, and Rose Gottemoeller all advocate will not be possible if the export control regulations (ITAR) and other restrictive policies currently in place are allowed to stand. U.S. export controls and international cooperation in space activities are closely linked. The ISS and the space shuttle program, as well as many of the successful robotic science missions, were accomplished with considerable international involvement and the relatively free exchange of data and (nonmilitary) technical information with partner nations. The ISS could not have been successful under any other conditions.

The NRC's report *Beyond 'Fortress America'* calls for a complete revision of the nation's export control regulations and asks the new administration to promptly revise export control policies by issuing an executive order that affirms "a strong presumption for openness."[42] (President Ronald Reagan signed just such an order during his administration.) The implementation of the report's recommendations would facilitate NASA's restructuring of its human space-exploration program with international partnerships.

President Obama, in his speech to the National Academy of Sciences on April 27, 2009, spoke of the need for international cooperation: "We also need to work with our friends around the world. Science, technology and innovation proceed more rapidly and more cost-effectively when insights, costs and risks are shared; and so many of the challenges that science and technology will help us meet are global in character."[43]

RECOMMENDATIONS

The First Barrier: The Impact of Export Controls on Space Commerce

Implement the recommendations of the NRC's January 2009 report, Beyond 'Fortress America.' *Beyond 'Fortress America'* presents a clear case for changing the present export control rules. The report calls on the new administration to revise export control policies promptly, by issuing an executive order that affirms "a strong presumption for openness." The report's twenty pages of recommendations should be implemented at the earliest possible date if the United States is to overcome this barrier to realizing the great potential of its present and planned activities in space, as well as strengthen the nation's university research activities and the nation's aerospace industry.

At a hearing of the Committee on Science and Technology of the U.S. House of Representatives on February 25, 2009, the witnesses and members discussed the findings and recommendations of *Beyond 'Fortress America,'* which states, "As currently structured, many of these controls undermine our national and homeland security and stifle American engagement in the global

42. National Research Council, *Beyond 'Fortress America.'*

43. Obama, "Remarks by the President."

economy, and in science and technology."[44] During the hearing, Committee Chairman Bart Gordon noted:

> Our nation's export controls were supposed to help strengthen our national security, by protecting America's sensitive technologies from falling into the wrong hands. However, in recent years there has been a growing chorus of concern that the current system of export controls is undermining our nation's competitiveness in the global economy, undermining our science and technology enterprise, and weakening our national security—not strengthening it.[45]

The Second Barrier: The Projected Shortfall in the U.S. Science and Engineering Workforce

Implement the recommendations made by the NRC reports Rising above the Gathering Storm *and* Beyond 'Fortress America.' *Rising above the Gathering Storm* probably best defines the problem facing the United States. The report and its recommendations were presented to the administration in 2005, and funds were authorized by Congress to implement the report's recommendations; however, only recently—with the FY2009 American Reinvestment and Recovery Act and the FY2009 regular appropriations—has Congress begun to appropriate the necessary funding. *Beyond 'Fortress America'* supports the visa policy recommendations of *Rising above the Gathering Storm*, stating that the present visa policy is seriously flawed, inhibiting collaboration with foreign experts and the absorption of foreign students into the United States workforce. Some encouraging signs suggest attention is being paid to the visa problem, but for those whose applications require "administrative review" the process is slow. The consequences for the future of the United States of failing to take prompt actions could be grave.

Pass an updated version of the 1958 National Defense Education Act, providing financial aid for education in the United States at all levels, both public and private. The present state of the U.S. educational system and the shortfall in engineering and science graduates coming out of U.S. universities should generate the same concern that was felt by the nation fifty years ago when the Russians launched *Sputnik*. The United States should be as motivated to solve today's problem as it was in 1958.[46]

Working with the nation's universities and drawing on their knowledge and expertise, NASA should provide support for a large, strong, and effective graduate student program. The National Defense Education Act, originally

44. National Research Council, *Beyond 'Fortress America.'*

45. House Committee on Science and Technology, Impacts of U.S. Export Control Policies on Science and Technology Activities and Competitiveness, 111th Cong., 1st sess., February 25, 2009.

46. The National Defense Education Act of 1958 (Public Law 85-864) provided aid to education in the United States at all levels, both public and private.

instituted in 1958, ensured the security of the nation by developing the mental resources and technical skills of its young men and women. Key features of the legislation included a student loan program for colleges and universities to increase the flow of students into science, mathematics, and foreign language careers; a National Defense Fellowship for graduate study toward a college teaching career; and a wide array of programs to enhance precollege teacher training and public understanding of science and technology. Combined with an active and meaningful partnership between NASA and the nation's universities, establishing a new National Defense Fellowship program could help to address the potential shortage of young U.S. scientists and engineers.

A key stated objective of all NASA research and technology programs should be to excite a new generation of scientists and engineers and rebuild scientific and technical expertise within NASA and across the nation. NASA's research center structure should be reestablished with this objective in mind, creating a strong link to the nation's universities.

The Third Barrier: Inadequate Planning For the Future of NASA and the U.S. Civilian Space Program

NASA should dedicate itself in the first term of the Obama administration to proving its relevance in the post–Cold War world while restructuring its human spaceflight objectives. We propose a new direction for NASA, a five-point plan that can be carried out with existing capabilities and realistic budgets.

Restructure the human space initiative, keeping the space shuttle flying until 2015. Extending space shuttle flights through 2015 would reduce reliance on Russia for transportation to the ISS and would provide the large up-and-down mass capability needed by all space station partners. The Constellation program should be restructured by canceling Ares I. Ares I, if successful, does not offer much of an advantage over other Earth-to-orbit launchers, and its development will take too long and use valuable funds. In addition, canceling other lunar surface-related work—including the lunar lander, the space suit, the rover, and other habitat and surface systems work—would focus the NASA workforce on immediate challenges. The cancelled activities could be resumed at an appropriate time in the future.

Postponing serious human-to-Mars discussions would be a pragmatic statement that recognizes the incredible challenges of a Mars mission. Robotic missions to Mars should be flown exclusively at least for the next decade, with extensive surface exploration by rovers.

The present Orion program should be restructured to reduce the size of the new spacecraft to a three-member crew, Apollo-size vehicle, or an X-38 lifting body vehicle with land-landing capability. The smaller-size vehicle could be flown on an Ariane 5 or Delta IV launch vehicle, with a planned 2014 or 2015 launch to the ISS. Moving to one of these launch vehicles allows a more rapid deployment by decoupling the new spacecraft from the development of a new launcher such as Ares I. Development of the new spacecraft would be accelerated by reducing the crew size and the need for weight efficiency and by taking advantage of previous Apollo and/or X-38 development. This would significantly reduce the technical risk in many key areas, such as thermal protection and parachutes. Weight and technical risk could be further reduced by designing the service module for space station service missions, making the module simpler.

By not investing in a unique Ares I Earth-to-orbit human launcher, NASA would be positioned to take full advantage of emerging commercial Earth-to-orbit transportation services, should opportunities develop in the 2015–2020 timeframe.

In our restructuring approach, the shift in near-term focus from the moon to the ISS would be followed by building a capability for a deep-space asteroid or comet intercept based on an Ares V heavy-lift vehicle. The Ares V heavy-lift launch capability is critical to any further deep-space exploration. By canceling Ares I, NASA should be able to focus all its launch vehicle development capability on designing the one launcher needed by the nation for future deep-space work and not anticipated to be provided by the private sector. All options for providing an Ares V heavyweight launch capability should be studied, including liquid boosters and liquid fly-back boosters, and international cooperative options. This should include the evaluation of options such as those proposed by the Direct Launcher concept, which makes use of most of the existing shuttle hardware, including the two solid rocket boosters and the external fuel tank, the only key modifications being an Apollo-like capsule at the top and an engine at the bottom of the external fuel tank. Although Ares I also uses shuttle parts, it is essentially an entirely new rocket.

The ability to fly to an asteroid would give the United States a lunar capability, should one be needed in the future. A deep-space mission, such as a human asteroid or comet intercept, would effectively demonstrate American leadership in space, should that be a concern in the face of a possible Chinese landing on the moon. Arguably, an American lunar return would do less to bolster U.S. space leadership than a more aggressive goal of performing a human asteroid intercept mission.

To advance this and other concepts, a joint NASA-Department of Defense propulsion research program should be initiated because propulsion is a limiting factor in space exploration. An aggressive program focused on innovative advanced propulsion development has been needed for a long time.

A restructured human spaceflight exploration initiative should involve and be supported by the capabilities of other U.S. federal agencies, universities, and industries, and be fully international in scope. The proven international partners from the ISS—Canada, Europe, Japan, and Russia—should be invited to participate in a restructured human space-exploration program.

Deliver short-term (within four years) payoffs in energy and the environment, especially climate change. The implementation to deliver short-term (within four years) payoffs in energy and the environment, especially in the area of climate change, takes advantage of the unique capabilities and skilled workforce of each NASA center. The efforts and unique capabilities of the various NASA centers should be refocused and assigned responsibilities commensurate with their expertise. The short-term payoffs would involve initiatives to fully understand and optimize the aerodynamics, structures, and mechanisms of large-scale wind turbines; to fully understand and optimize high-efficiency, large-scale solar cells and small-scale fuel cell technology applications; to improve aerodynamic and propulsion efficiency of general aviation and commercial aircraft; and to develop and evaluate alternative aviation fuels and aircraft power plants.

Initiatives should be implemented to fully employ NASA's ability to monitor, model, and predict long-term climate, utilizing NASA instruments, aircraft, spacecraft, computers, and communications. This effort could include enhanced use of the ISS for monitoring Earth, as well as expansion of the current EOS, and would require close coordination with the National Oceanic and Atmospheric Administration (NOAA), U.S. Geological Survey (USGS), and the National Center for Atmospheric Research (NCAR), supported by the NSF through the president's National Science and Technology Council. The NRC's 2007 *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond* (a report of the Committee on Earth Science and Applications from Space: A Community Assessment and Strategy for the Future) provides a national strategy for the implementation of a program of scientific discovery and development of applications for the next decade that forms an excellent foundation for needed research that will significantly enhance our understanding of our global environment. The report recommends additional missions over and above the present planned program.[47]

In addition, robotic exploration should be implemented to compare Earth to sister planets, a project that could lead to a better understanding of the climate history of Earth. Breakthroughs in all of these areas, as well as the development of better solar and fuel cells and improved knowledge of the environment and planetology, are essential to future exploration activities.

Deliver longer-term payoffs (within four to eight years) for energy and the environment. The implementation to deliver longer-term payoffs (four to eight years) for energy and the environment as a potential long-term energy solution could involve an effort to demonstrate—initially on a small scale—wireless power transmission from orbit to Earth using the shuttle and the ISS. Full implementation of a space-based solar power system requires a larger and less costly launch infrastructure than is currently available. Such a system will not be feasible until launch costs can be reduced. However, a low-Earth-orbit demonstration, potentially based on the shuttle or the ISS, would help scien-

47. National Research Council, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond* (Washington, D.C.: National Academies Press, 2007).

tists and engineers understand the problems and required efficiencies. This concept has made major strides since its initial inception with the realization that constellations of smaller, more efficient solar collectors in medium-Earth orbit can provide the same capability as larger, high-orbit satellites. Demonstrating space-based solar power on a small scale would help scientists and engineers better understand what needs to be done to utilize this concept for supplying electrical power needs. Additional small-scale efforts could be initiated to demonstrate other potential technologies for healing the planet that are tied to NASA's ability to monitor, model, and engineer large-scale complex systems.

Ensure an ongoing and effective robotic space science program. Spectacular scientific discoveries and advances have been one of NASA's major achievements since its founding a half-century ago. Today, NASA supports an outstanding community of researchers interested in continuing to make pathbreaking discoveries about the workings—past, present, and future—of the universe, solar system, and Earth through space-based telescopes, observations, satellites, and planetary rovers. That community needs a commitment from NASA that researchers will not be left in the lurch if they bet their careers on instruments that, through peer review, are judged to be excellent and that can be accommodated within NASA's budget.

Reinvigorate and pursue an effective aeronautical research program, with particular attention to low-carbon fuels and efficiency. Aeronautical capabilities are important to the U.S. economy, but the aeronautics segment is becoming increasingly less competitive. The U.S. share of the world aerospace markets has declined significantly since the mid-1980s. In the past, the NASA aeronautics research and technology program has produced significant advances in aeronautical design. The low-drag cowl for radial engines and the "Coke-bottle" to reduce transonic drag rise are but two examples of the benefits gained from NASA's aeronautical research program.

More recent aeronautics advances—such as multi-axis thrust vectoring exhaust nozzles integrated with aircraft flight-control systems; fly-by-wire flight control technologies; high-strength, high-stiffness fiber composite structures; and tilt-wing rotorcraft technology—have been achieved in partnership with NASA's research and technology programs. Modern aircraft are complex "systems of systems," and advances in one discipline, such as aerodynamics, may require an advance in another discipline, such as structures, before they can be applied in a new aircraft design. A NASA fundamental aeronautical research and technology program, not tied to specific development projects, would be an essential element of the reinvigorated aeronautics initiative and would provide the foundation for future advancements.

Government aeronautical test facilities are another area of concern. Many facilities have been or are being closed. U.S. aircraft companies are going overseas to perform wind tunnel testing of new U.S. designs. A reinvigorated and more effective aeronautical research program must include a review of the present status of the nation's aeronautical test facilities and should identify the upgrades and new construction needed to ensure the support of a revitalized aeronautical research program.

Our proposed five-point plan takes the agency in a direction that will significantly contribute to the future in two vital areas: energy and the environment, particularly climate change. NASA will continue to fly humans in space, complete the ISS, meet its commitments to the United States' international partners, and reestablish a balanced set of activities featuring science, engineering, aeronautics, research, and technology. NASA should also build a foundation for a human space-exploration program that involves other agencies and the nation's universities and is based on international cooperation.

As a part of this restructuring, greater authority and responsibility should be returned to the directors of NASA's research centers. The full cost accounting constraints that require projects to pay for personnel, and for all personnel to be paid by projects, would be removed. Personnel would be funded from a common pool as they were throughout NASA's history prior to recent times. Full cost accounting requires each engineer or scientist to be supported by a program and does not allow for an organization of engineers and scientists devoted to research and development, a constraint that all but eliminates the agency's ability to build and retain its technical and scientific expertise.

The Fourth Barrier: The Erosion of International Cooperation in Space

Restructure the goals of the human space exploration initiative by de-emphasizing an early focus on the U.S.-led moon and Mars program in favor of enhanced support for the ISS and a clearly stated objective of peaceful cooperation in space based on scientific research.

Extend space shuttle flights through 2015, thereby reducing reliance on Russia for transportation to the ISS and providing the large up-and-down mass capability needed by all ISS partners. NASA studies have shown that the space shuttle could be safely flown, at a reduced flight rate, through 2015. This would preserve America's independent access to space and would also preserve much of the current workforce and provide a smoother transition between programs. These flights would provide essential support to the ISS and would allow the United States to meet its commitments to its international partners.

Change the focus from an early moon and Mars mission to enhanced support of the ISS past 2015. A clearly stated rationale for the ISS, such as continued international cooperation on the peaceful uses of space, scientific research in particular, would be important.

Encourage participation in a restructured human space exploration initiative by other federal agencies, the university community, and scientists in other nations —including the U.S.'s ISS partners but expanded to include all interested countries, such as China. China has joined the United States and Russia in having the capability to fly human beings in space, and China is planning for its own space station. As Susan Eisenhower has outlined, the benefits to the United States of cooperation in space with Russia and of working with it and the other international partners on the ISS, could be extended by making China a partner on the ISS, thus encouraging and turning China's aspirations in space toward cooperation and the peaceful use of space.[48] As a prelude to such discussions, the United States should initiate discussions with China on the use of a common docking system that would enhance and enable space rescue missions. The successful docking system used for the ISS is an enhancement of the system developed and demonstrated on the Apollo-Soyuz mission of July 1975. We understand that both the United States and China have strategic national security interests in space. But, in our view, the peaceful uses of space should be the ultimate goal of both nations, and the surest way to achieve that objective is to begin serious discussions on cooperative scientific and human space-exploration activities that the two countries, in cooperation with other nations, can plan and carry out in the coming decades.

CONCLUSION

The election of President Obama and the arrival of an administration with a progressive agenda presents NASA with a unique opportunity to demonstrate that it is every bit as relevant in the post–Cold War world as it was in the days following *Sputnik*. By focusing the agency's legendary capabilities on some of the nation's most critical needs while restructuring its human spaceflight objectives and establishing a more balanced overall set of programs that retain science as a top priority, NASA could emerge a stronger agency than at any time in recent decades. We propose a new direction for NASA, a plan that can be carried out with existing capabilities and realistic budgets.[49]

In the short term, NASA's deep-space human spaceflight efforts can be rapidly redirected from the moon and Mars to focus again on the ISS and on science and the technical issues related to energy and the environment by placing greater emphasis on research on Earth and in low-Earth orbit, including enhanced satellite Earth-observation systems. At the same time, NASA can—and should—plan, with international partners, including the present ISS partners and China, for a truly visionary cooperative space exploration program beyond Earth orbit. Such a program would serve to inspire the next generation of engineers and explorers as we seek new and challenging frontiers in space.

Energy security and threats to the environment—particularly climate change and its impact on Earth's ecology, land surfaces, oceans, and people—will be one of the most significant challenges humankind will face in the next

48. Eisenhower, *Partners in Space*.

49. In addition to the present paper, see also, George W. S. Abbey, Neal Lane, and John Muratore, "Maximizing NASA's Potential in Flight and on the Ground: Recommendations for the Next Administration," James A. Baker III Institute for Public Policy, January 20, 2009.

fifty years and well beyond. National and domestic security, foreign policy, the economy, and social equality will be increasingly dependent on how the United States responds to these two challenges. NASA has three great resources to make significant contributions in these areas: its ability to operate in space and air; its decades of experience in modeling and managing large-scale scientific projects; and its extensive engineering experience with alternative fuels and energy systems.

Since the launch of the first Landsat satellite in the 1970s, NASA has provided an extraordinary vantage point for and played a critical role in observing Earth's environment. Unfortunately, NASA has been reluctant to significantly publicize its efforts, in part because of the political controversy surrounding global warming and climate change. Today the global threat of climate change is much clearer than it might have been even a decade ago, thanks to recent progress in climate science, observations, and climate modeling. With the new administration committed to playing a leadership role domestically and globally in mitigating climate change, U.S. policy-makers must have access to the best available scientific information—much of that coming from satellite observations. NASA is the only federal agency that has the scientific, engineering, and technical capability to design and launch the satellites that are needed for Earth observations.

NASA's decades of experience in modeling and managing large-scale processes and projects is another asset, one coupled with tools such as sophisticated computer modeling, large-scale high-performance computing, modern aircraft, and communications (satellite and ground). A strong partnership among NASA, NOAA (which has major responsibilities for weather and climate predictions), the USGS, and NCAR, supported by the NSF, is critical to future U.S. capability in weather forecasting and climate projections. The required level of coordination and collaboration on specific projects will require an unprecedented degree of agency-to-agency cooperation. That, in turn, will require the encouragement and active support of the Office of Science and Technology Policy, the Office of Management and Budget, and other offices of the White House.

Finally, because of its unique mission, NASA has developed extensive engineering experience with alternative fuels and energy systems, such as wind turbines, solar cell arrays, batteries, and fuel cells. NASA is the primary federal agency with the experience to improve the fuel efficiency of all types of aircraft. These capabilities have not been in the public eye but, nevertheless, have been essential to the success of NASA missions since its creation immediately after the launch of *Sputnik*. These capabilities need to be publicly acknowledged so that the larger value of NASA's contributions over the decades can be appreciated by the American public and their elected representatives in Congress.

We recognize that we may seem to be encouraging an already stretched agency to extend itself even further. In fact, what we are recommending is to optimize what NASA already has the ability to do well. We are recommending a relatively low-risk but high-payoff vision for NASA that would place it high on the list of America's current priorities.

By capitalizing on its substantial expertise, accomplishments, and capabilities, NASA can demonstrate its importance as one of the nation's leading science and technology agencies in helping to resolve two of the major challenges facing the United States today: energy security and climate change. At the same time, NASA can reassert its international leadership role in space science and exploration as it restructures its human spaceflight activities and reembarks on a balanced program of space-based science and aeronautics research.

Many of the recommendations in the 2005 NRC report *Rising above the Gathering Storm* and in the 2007 America COMPETES Act would be supported by a NASA encouraged to pursue international cooperation and redirected to focus on a sound and balanced civil program of space science, exploration, environmental research, and aeronautics research and technology. Moreover, the result would be a civil space program that would allow the United States to maintain the leadership envisioned by President Kennedy in his historic Rice University speech in 1962:

> [T]he vows of this Nation can only be fulfilled if we in this Nation are first, and, therefore, we intend to be first. In short, our leadership in science and in industry, our hopes for peace and security, our obligations to ourselves as well as others, all require us to make this effort, to solve these mysteries, to solve them for the good of all men, and to become the world's leading space-faring nation.[50]

Today, with the Cold War far behind us, the United States can be the leading spacefaring nation by making the necessary investments in research, education, and human space exploration and by leveraging those investments through meaningful cooperation with other nations.[51]

50. Kennedy, "Address at Rice University on the Nation's Space Effort."

51. The authors would like to acknowledge John F. Muratore for his contributions to the assessment and recommendations concerning the future of NASA and the U.S. civilian space program.

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