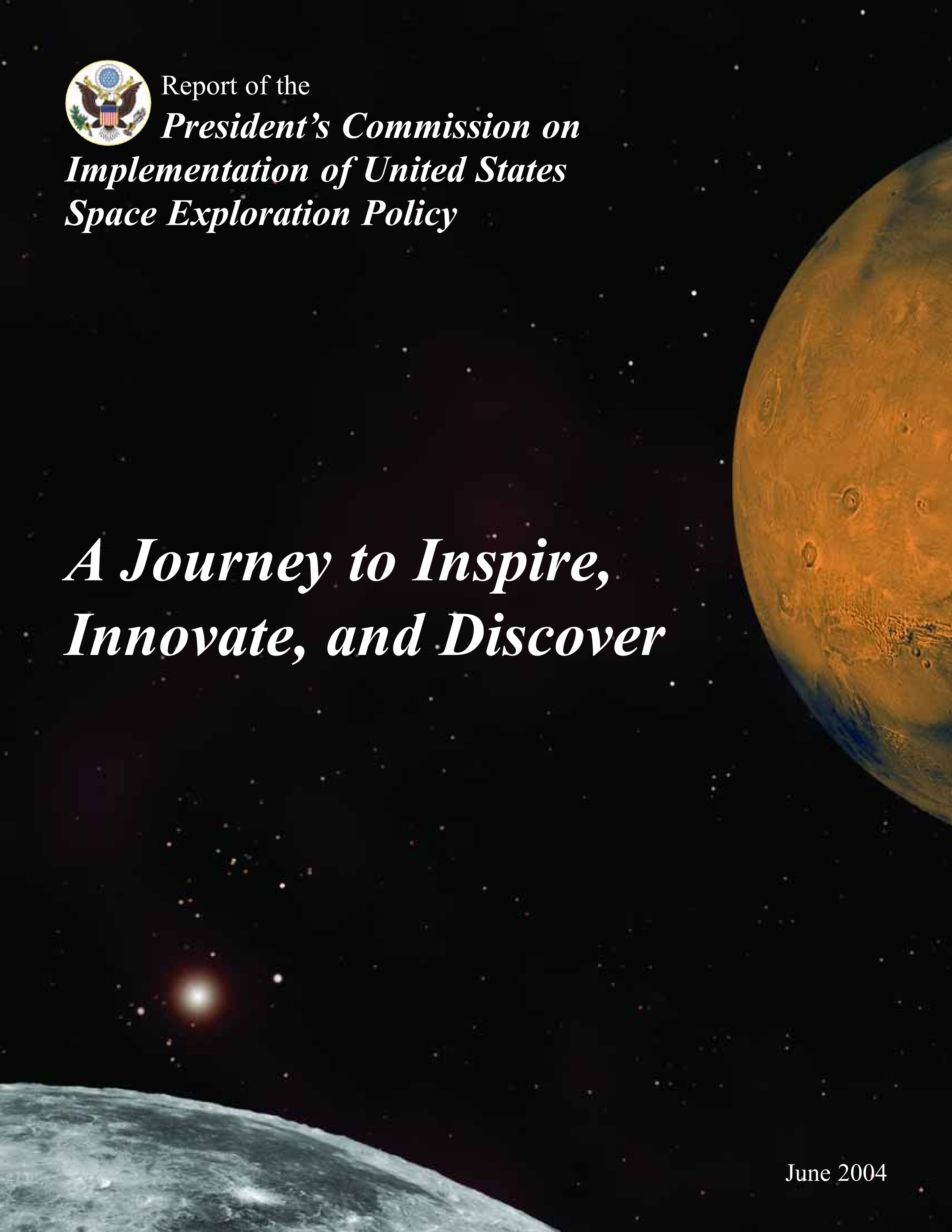
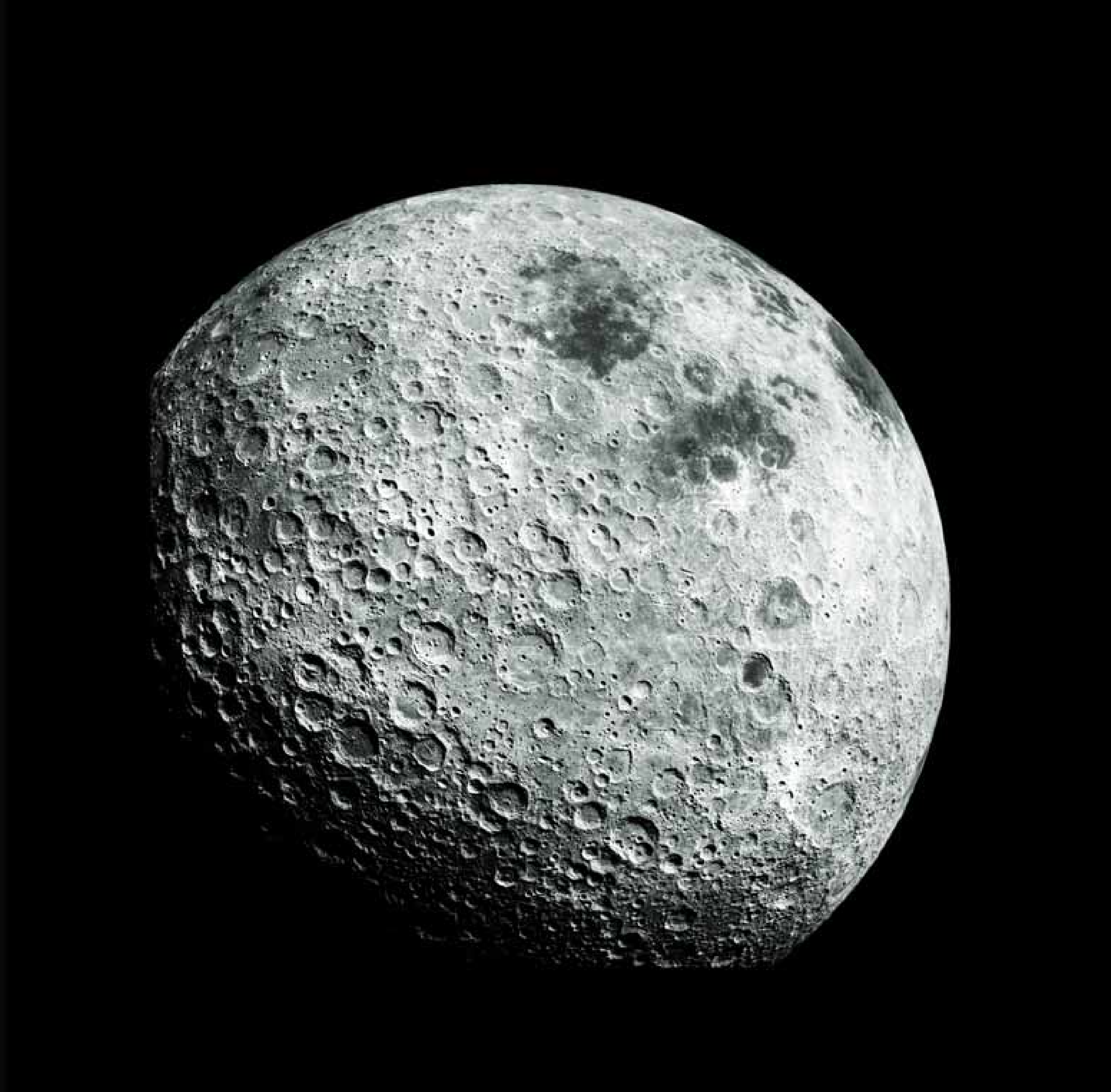
Report of the

President's Commission on Implementation of United States Space Exploration Policy



A Journey to Inspire, Innovate, and Discover

June 2004



Report of the

President's Commission on Implementation of United States Space Exploration Policy

A Journey to Inspire, Innovate, and Discover

June 2004

Moon, Mars and Beyond …

Transmittal Letter

June 4, 2004

The Honorable George W. Bush
President of the United States
The White House
Washington, D.C. 20500

Dear Mr. President:

On January 14, 2004, you announced a new vision for the United States civil space program based upon exploration of the Moon, Mars, and beyond. The Executive Order you signed on January 27, 2004, created a Commission to examine and make recommendations on implementing this new vision and asked the Commission to submit its report 120 days after its first meeting.

In accordance with your direction, enclosed is the Commission's final report, *A Journey to Inspire, Innovate, and Discover*.

The Commission sought extensive input for our deliberations, from within the U.S. government and directly from the public in the United States and abroad. We held five televised public hearings, meeting in: Washington, D.C.; Dayton, Ohio; Atlanta, Georgia; San Francisco, California; and New York City. We heard public testimony from 96 individuals representing academia, industry, media, teachers, students, entrepreneurs, astronauts, labor unions, state governments, federal government agencies, international space agencies, and professional associations. The Commission's web site received more than 6 million hits and over 6,000 written inputs. Public comments strongly supported the new space vision, by a 7-to-1 ratio.

The Commission fully supports your vision and finds that this journey of exploration will sustain vital national objectives here on Earth. It will provide inspiration for our youth to enter technical fields, generate economic benefit to our nation through the creation of additional technical jobs, improve the competitiveness of our industrial base in the world marketplace, provide clear recognition of America's leadership, and improve prosperity and the quality of life for all Americans.

We conclude that fundamental changes must take place in how the nation approaches space exploration and manages the vision for success. This national effort calls for a transformation of NASA, building a robust international space industry, a discovery-based science agenda, and educational initiatives to support youth and teachers inspired by the vision.

Sincerely yours,

E. C. "Pete" Aldridge, Jr.
Chairman

Commissioners

Edward C. "Pete" Aldridge, Jr.
Chairman

Carleton S. Fiorina

Michael P. Jackson

Laurie A. Leshin

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Paul D. Spudis

Neil deGrasse Tyson

Robert S. Walker

Maria T. Zuber

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Executive Summary

On January 14, 2004, President George W. Bush announced a new vision for America's civil space program that calls for human and robotic missions to the Moon, Mars, and beyond. This vision set forth goals of: returning the Space Shuttle safely to flight; completing the International Space Station (ISS); phasing out the Space Shuttle when the ISS is complete (about 2010); sending a robotic orbiter and lander to the Moon; sending a human expedition to the Moon as early as 2015, but no later than 2020; conducting robotic missions to Mars in preparation for a future human expedition; and conducting robotic exploration across the solar system. Such a focus for the American space program has not existed since the Apollo era and establishes a much-needed direction and purpose for our national space efforts.

While discovery is the goal of space exploration, the Commission is certain that the benefits here on Earth will make the journey at least as important as the destination.

The long-term, ambitious space agenda advanced by the President for robotic and human exploration will significantly help the United States protect its technological leadership, economic vitality, and security. This ambitious path of exploration and the achievements made along the way will inspire the nation's youth, yield scientific breakthroughs, create high technology jobs, improve our industrial competitiveness, demonstrate America's leadership, and improve prosperity and the quality of life for all Americans.

To sustain this program over many Presidential Administrations and Congressional sessions, our leaders must routinely explain and demonstrate the value, affordability, and credibility of the program to all Americans so that they accept ownership of it. The President has projected the annual resources available to NASA at roughly the same level as in the past, growing only slightly in the coming years. Within these annual levels, the journey will need to be managed within available resources using a "go as you can pay" approach, which allows specific exploration goals to be adjusted as technology advances and periodic milestones are achieved.

Successful implementation of the national space exploration vision will require significant cultural and organizational changes in the federal government's approach to managing the effort, and bold transformation initiatives must be undertaken. The Commission has developed the following findings and recommendations for a sustainable, affordable, and credible program:

- ➢ **The space exploration vision must be managed as a significant national priority, a shared commitment of the President, Congress, and the American people.** The Commission recommends:
  - ✧ The President establish a permanent Space Exploration Steering Council, reporting to the President, with representatives of all appropriate federal agencies, and chaired by the Vice President or such other senior White House executive that the President may designate. The council shall be empowered to develop policies and coordinate work by its agencies to share technologies, facilities, and talent with NASA to support the national space exploration vision.

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

  - ✧ NASA recognize and implement a far larger presence of private industry in space operations with the specific goal of allowing private industry to assume the primary role of providing services to NASA, and most immediately in accessing low-Earth orbit. In NASA decisions, the preferred choice for operational activities must be competitively awarded contracts with private and non-profit organizations and NASA's role must be limited to only those areas where there is irrefutable demonstration that only government can perform the proposed activity;

  - ✧ NASA be transformed to become more focused and effectively integrated to implement the national space exploration vision, with a structure that affixes clear authority and accountability;

  - ✧ NASA Centers be reconfigured as Federally Funded Research and Development Centers to enable innovation, to work effectively with the private sector, and to stimulate economic development. The Commission recognizes that certain specific functions should remain under federal management within a reconfigured Center;

  - ✧ the Administration and Congress work with NASA to create 3 new NASA organizations:
    - a technical advisory board that would give the Administrator and NASA leadership independent and responsive advice on technology and risk mitigation plans;
    - an independent cost estimating organization to ensure cost realism and accuracy; and
    - a research and technology organization that sponsors high risk/high payoff technology advancement while tolerating periodic failures; and

  - ✧ NASA adopt proven personnel and management reforms to implement the national space exploration vision, to include:
    - use of "system-of-systems" approach;
    - policies of spiral, evolutionary development;
    - reliance upon lead systems integrators; and
    - independent technical and cost assessments.

The long-term, ambitious space agenda advanced by the President for robotic and human exploration will significantly help the United States protect its technological leadership, economic vitality, and security.

- **The successful development of identified enabling technologies will be critical to attainment of exploration objectives within reasonable schedules and affordable costs.** The Commission recommends:

  - ✧ NASA immediately form special project teams for each enabling technology to:
    - conduct initial assessments of these technologies;
    - develop a roadmap that leads to mature technologies;
    - integrate these technologies into the exploration architecture; and
    - develop a plan for transition of appropriate technologies to the private sector.

➢ **Sustaining the long-term exploration of the solar system requires a robust space industry that will contribute to national economic growth, produce new products through the creation of new knowledge, and lead the world in invention and innovation. This space industry will become a national treasure.** The Commission recommends:

- ✧ NASA aggressively use its contractual authority to reach broadly into the commercial and nonprofit communities to bring the best ideas, technologies, and management tools into the accomplishment of exploration goals; and

- ✧ Congress increase the potential for commercial opportunities related to the national space exploration vision by providing incentives for entrepreneurial investment in space, by creating significant monetary prizes for the accomplishment of space missions and/or technology developments and by assuring appropriate property rights for those who seek to develop space resources and infrastructure.

- ➢ **International talents and technologies will be of significant value in successfully implementing the space exploration vision, and tapping into the global marketplace is consistent with our core value of using private sector resources to meet mission goals.** The Commission recommends:

  - ✧ NASA pursue international partnerships based upon an architecture that would encourage global investment in support of the vision.

- ➢ **Implementing the space exploration vision will be enabled by scientific knowledge, and will enable compelling scientific opportunities to study Earth and its environs, the solar system, other planetary systems, and the universe.** The Commission recommends:

  - ✧ NASA seeks routine input from the scientific community on exploration architectures to ensure that maximum use is made of existing assets and emerging capabilities;

  - ✧ NASA ask the National Academy of Sciences to engage the scientific community in a re-evaluation of priorities to exploit opportunities created by the space exploration vision. In particular, the community should consider how machines and humans, used separately and in combination, can maximize scientific returns; and

  - ✧ a discovery-based criterion to select destinations beyond the Moon and Mars that also considers affordability, technical maturity, scientific importance, and emerging capabilities including access to *in-situ* space resources.

- ➢ **The space exploration vision offers an extraordinary opportunity to stimulate mathematics, science, and engineering excellence for America's students and teachers – and to engage the public in a journey that will shape the course of human destiny.** The Commission recommends:

  - ✧ The Space Exploration Steering Council work with America's education community and state and local political leaders to produce an action plan that leverages the exploration vision in support of the nation's commitment to improve math, science, and engineering education. The action plan should:
    - increase the priority on teacher training;
    - provide for better integration of existing math, science, and engineering education initiatives across governments, industries, and professional organizations; and
    - explore options to create a university-based "virtual space academy" for training the next generation technical work force.

  - ✧ Industry, professional organizations, and the media engage the public in understanding why space exploration is vital to our scientific, economic, and security interests.

The Commission unanimously endorses this ambitious yet thoroughly achievable goal of space exploration. This will require a steady commitment from current and future Administrations, Congresses, and the American people. Reasonable risk must be accommodated, along with some failures. Our journey will require the government to embrace fundamental changes in its management and organization. This exploration vision must be discovery driven – and it must certainly necessitate placing greater reliance on the private sector. We should take advantage of this unique opportunity to inspire our youth, motivate our teachers and improve math, science, and engineering education for our future workforce. In fact, we must do all of these things to succeed.

Section I

Introduction: The Space Exploration Vision

A. Overview of the Space Exploration Vision

On January 14, 2004, President George W. Bush announced a new space exploration vision for America's civil space program. He set out four goals:

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

In addition, the President renewed the nation's commitment to return the Space Shuttle safely to flight, complete assembly of the International Space Station and meet our international obligations to support its use, and retire the Space Shuttle after the space station is complete. He outlined 19 specific tasks that, collectively, further define the timetable, scope, and conduct for implementation of the space exploration vision. These tasks address: (a) exploration activities in low-Earth orbit; (b) space exploration beyond low-Earth orbit; (c) space transportation capabilities supporting exploration; and (d) international and commercial participation (see Appendix C for the complete text).

These goals lay out an astonishingly ambitious vision. Our objectives in space have been radically transformed – a return to the Moon, missions to Mars, and beyond. A successfully implemented vision will create a sustained capability in space for the nation.

These goals lay out an astonishingly ambitious vision. Our objectives in space have been radically transformed – a return to the Moon, missions to Mars, and beyond. A successfully implemented vision will create a sustained capability in space for the nation.

B. The Commission

On January 27, 2004, the President signed an Executive Order creating a Presidential Commission "to obtain recommendations concerning implementation of the new vision for space exploration activities of the United States." The Commission was chartered to make recommendations to the President on:

1. a science research agenda to be conducted on the Moon and other destinations as well as human and robotic science activities that advance our capacity to achieve the policy;

2. the exploration of technologies, demonstrations, and strategies, including the use of lunar and other *in situ* natural resources, that could be used for sustainable human and robotic exploration;
3. criteria that could be used to select future destinations for human exploration;
4. long-term organization options for managing implementation of space exploration activities;
5. the most appropriate and effective roles for potential private-sector and international participants in implementing the policy;
6. methods for optimizing space exploration activities to encourage the interest of America's youth in studying and pursuing careers in mathematics, science, and engineering; and
7. management of the implementation of the policy within available resources.

The nine Commissioners appointed by the President come from industry, government service, academia, and the military. Collectively, they have experience in space operations, technology, space science, and senior federal government management (see appendix D for Member Biographies). The Commission conducted extensive public outreach, as described in the chairman's transmittal letter and in several appendices to this report.

This report represents the consensus recommendations of all nine Commissioners.

C. Why Go?

Explaining his space exploration vision, the President said "the fundamental goal of this vision is to advance U.S. scientific, security, and economic interests through a robust space exploration program." Discussion of these and other complementary benefits were among the most persistent and compelling themes of the Commission's public hearings, and of the over 6,000 other formal submissions we received.

The discussion about a national vision for space exploration should be more about how to proceed, than about whether to go. The issues associated with how best to organize for success are the chief focus of this report.

A consensus to embrace this bold challenge to journey into space has not yet been completely forged. Congress and the American people have both the need and responsibility to understand the vision fully, deliberate on the matter, and render a decision. We hope this report will contribute to that discussion and decision.

The further exploration of space will accrue enormous practical dividends here on Earth, captured in three fundamental themes: exploration, growth, security.

(1) Exploration. Exploring the Moon, Mars, and beyond is a great journey worthy of a great nation. The impulse to explore the unknown is a human imperative, and a notable part of what animates us as a people. This endeavor presents an opportunity to inspire a new generation of American explorers, scientists, entrepreneurs, and innovators who will provide positive American leadership to the world.

Ray Bradbury, celebrated author of *The Martian Chronicles*, testified to the Commission about the importance of exploration. When presented with this challenge of travel to Mars, he said, "Our children will point to the sky and say YES!" Whether for youth or adults, exploration broadens the imagination. And by stretching to understand the unknown, we build and sustain our nation's intellectual capital.

Despite the spiritual, emotional, and intellectual appeal of a journey to space – exploration and discovery will perhaps *not* be sufficient drivers to sustain what will be a long, and at times risky, journey. We must also undertake this mission for pragmatic, but no less compelling reasons, which have everything to do with life here on Earth.

(2) Growth. Further space exploration will generate new jobs within current industries and will likely spawn entire new markets involving leading-edge manufacturing and flight support services. The vision requires a large, high-tech manufacturing base and a skilled workforce. As one impressive labor leader testified to the Commission, "every dollar spent on space is a dollar spent here on Earth." This focus is good for jobs, good for the economy, and good for American families.

Moreover, the positive economic effects of this national effort will not be limited to the aerospace industry. The public record is rich with data about how aerospace technology and pure space research routinely spur other tangible advances and unrelated economic opportunity. Thousands of inventions and manufacturing breakthroughs derived from our space program now find uses in everyday life. They range from insulin pumps based on technology used in the Mars Viking spacecraft, to forest firefighting tools derived from space-based infrared camera technology.

(3) Security. Implementation of the vision is also important to the nation's domestic, international, and economic security. Regarding domestic security, the Commission heard testimony that skills honed in implementing the vision could help detect and deflect harmful asteroids that could one day threaten Earth. Just recently the subject of science fiction novels and movie thrillers, such capability is now the focus of legitimate scientific investigation.

Much of the United States' current military strength and economic security rests on our technology leadership. Our technological and industrial base must constantly be renewed. Therefore, the United States must continue to lead, especially in those industries that require, and therefore build, technology skills. In addition to the aerospace industry itself, implementation of the space vision will rely upon, and thus drive, a broad spectrum of technology-driven disciplines, such as medical research, biotechnology, computing, nanotechnology, advanced composite manufacturing, and many others.

Economic security is also a function of long-term competitiveness. Although the era of Sputnik has given way to an age of international cooperation in space, it remains a competitive frontier. The President rightfully indicated that the vision calls for "a journey, not a race" and he invites "other nations to join us on this journey, in the spirit of cooperation and friendship." But with any journey, someone must chart the course and then lead the way. Other nations, against whom we compete for jobs in the global economy, are also intent on exploring space. If not us, someone else will lead in the exploration, utilization and, ultimately, the commercialization of space, as we sit idly by.

Long-term competitiveness requires a skilled workforce. The space exploration vision can be a catalyst for a much-needed renaissance in math and science education in the United States. The ability of our children to compete and prosper in the 21st century continues to decline. Comparing our competence with that of other nations in math, science, computer literacy, and engineering – 21st century equivalents of the 3Rs – we are becoming less, not more, competitive.[1] To compete in a knowledge economy, high-tech industries require these particular skills. The space exploration mission can be an important part of our national effort to galvanize and reform our educational system.

1. There are many reports documenting the scope and breadth of this decline, certainly even preceding the landmark study *A Nation at Risk* (1983), which concluded that "our once unchallenged preeminence in commerce, industry, science, and technological innovation is being overtaken by competitors throughout the world… . If an unfriendly foreign power had attempted to impose on America the mediocre educational performance that exists today, we might well have viewed it as an act of war." As the Commission began its final public hearing, which was held in New York, a front-page story in *The New York Times,* reported, "National Science Panel Warns of Far Too Few New Scientists," May 5, 2004.

In summary the United States can ill-afford puny ambitions in space. Going to the Moon, Mars, and beyond may be our destination and our goal, but the *journey* towards this goal and what it means here on Earth, is what really matters. Space exploration is an opportunity to invest meaningfully in America. It is a much-needed opportunity to revitalize our industrial base and nurture the skills needed to drive a new generation of American innovation.

Finding 1

The Commission finds that the long-term, ambitious space agenda advanced by the President for robotic and human exploration will significantly help the United States protect its technological leadership, economic vitality, and security.

D. Three Imperatives for Success

Three imperatives must continuously animate the nation's space exploration journey. It must be: (1) sustainable over several decades; (2) affordable with available resources; and (3) credible in the stewardship of taxpayer dollars.

(1) Sustainability. Together, just one Presidential Administration working with one Congress can successfully launch America's new exploration journey. But the space exploration vision sets a complex course that must be sustained for several decades. Obviously, this will require the support of multiple Presidents, multiple Congresses, and a couple of generations of American taxpayers. And at its core, the vision requires a sustained commitment from the American public. How can we forge a sustainable commitment for this complex and long-term enterprise?

To be sustainable over many decades, the government's space exploration plan must include:

- a strong justification easily articulated and understood;
- effective tools to explain this vision to the American public;
- regular, visible demonstrations of ongoing progress and success;
- an affordable plan that does not require huge peaks in annual funding; and
- support from a robust space industry, providing jobs and technology for the nation.

Public ownership of this agenda must be broad, deep, and nonpartisan. Mercury, Gemini, and Apollo astronauts did not really belong to NASA, but to the public. That was just one manifestation of public ownership of NASA during that era. We heard from many in the public and the aerospace industry how President Kennedy's challenge to land a man on the Moon affected an entire generation. One witness from the government said simply, "We all wanted to go."

The bulk of this report is about strategies to implement the vision for space exploration in way that justifies the confidence, enthusiasm, and sustained support of the American people. To achieve that, the vision's implementation plan must also be deemed affordable.

(2) Affordability. One individual, testifying at the Commission's San Francisco hearing, speculated that if curing the social ills of large cities had been a precondition for launching the Lewis and Clark expedition, all Americans would still be living on the East Coast. At the outset of our new space journey, however, it is essential to assess its affordability, carefully and dispassionately.

Perhaps the first task is to decide whether the mission is worth doing. The United States has long proved itself wealthy enough to finance many important national priorities simultaneously. Space exploration should remain one among them. In fact, the Commission concludes that by supporting this journey, America will sustain vital national objectives, and also improve life on Earth.

Before launching the journey, some might be inclined first to demand an accounting for the full cost of the roundtrip ticket. After all, this is how we make nearly all spending decisions in public and private life. However, we cannot provide accurate cost projections for the optimal mix of robotic and human missions to the Moon and Mars conducted over the next three decades. How can one today determine the price, for example, of Mars spacecraft for humans that are only now beginning to be imagined? Demanding such precision at this early time would represent a fundamental misunderstanding of the dynamics of this discovery-driven and multi-phased journey.

Instead, the President proposes to implement this space strategy in a series of incremental steps. Each is funded from a baseline defined by the current level of funding for our existing civil space initiatives. He proposes not one mission, but a progressively complex series of missions. Each builds on the shoulders of its predecessor "with measurable milestones" and each is "***executed on the basis of available resources,*** accumulated experience, and technology readiness."[2] Chapter II presents specific recommendations about how the federal government should structure and manage its complex technology procurements in support of the vision, through a series of "spiral, evolutionary developments."

The vision is a "go as you can pay" plan where we achieve periodic technological advances and discoveries based on what we can afford annually.

This approach to procurement and budgeting is certainly reasonable. It is consistent with how the United States funds other major national commitments, such as cancer research. Our goal in fighting cancer is clear: a cure. Our commitment to that journey is undoubted. In our unbounded optimism there is only one uncertainty: how long will it take to find the cure? The pace of cancer research, but not the outcome, is defined by a tough, prudential judgment: annually, how much can we afford?[3]

The space exploration agenda is cut from this same pattern. It is a "go as you can pay" plan where we achieve periodic milestones, technological advances, and discoveries based on what we can afford annually.[4] After the Space Shuttle is retired, and as our commitment aboard the International Space Station approaches fulfillment, what else should we do in space? We cannot wait another decade to answer that question. Without the clarity of a long-term vision, NASA's annual expenditures would be spent on a vastly more diffuse portfolio of projects in the service of no coherent goal. With focus that comes from the vision, this same amount of annual funding can achieve profound and productive success.

2. *A Renewed Spirit of Discovery* (emphasis added).
3. The Commission notes with satisfaction that NASA's space innovations have added significantly to cancer research and treatment breakthroughs.
4. The President's FY05 budget proposes to begin funding in support of the exploration agenda in FY05, to increase NASA's overall budget to $18 billion by FY09, and grow NASA's budget by inflation thereafter. Compared with FY04, most of the five-year growth at NASA is associated with returning the Shuttle to flight. See Appendix F for further detail regarding historical funding levels for NASA and the Administration's initial budget proposal in support of the space exploration vision.

The U.S. government need not shoulder the entire cost for implementation of the vision. The Commission believes there will be significant private sector and international investment, if the recommendations made herein are adopted. For example, we are persuaded that the award of significant monetary "prizes" tied directly to the vision plan will spark entrepreneurial investment globally and accelerate the development of technologies and systems that enable travel to the Moon and Mars. In our hearings, the Commission also heard from state governments that are prepared to invest in America's space infrastructure, if those investments can be appropriately tied to their own economic growth.

Proper coordination with other nations will also yield alignment of missions for mutual scientific advantage and will bring cost savings that benefit all parties. America's direct financial investment should be designed to leverage all such private and public investments. These monies, when added to what the federal government can afford, will indeed get us to the Moon, Mars, and beyond.

The real question is not whether current levels of federal investment alone are adequate, but how can we best recruit and coordinate a larger team in support of the plan?

(3) Credibility. Support for this endeavor must come with a commitment from NASA – and all its partners – to good stewardship. Above all, the space exploration vision is neither sustainable nor affordable unless NASA's leadership of the exploration vision is deemed credible by the public and Congress. NASA will continue to operate under a bright light of scrutiny. They must embrace best practices of program management, certainly from the public sector, but also from the private sector. At all levels, NASA must be relentlessly innovative and institutionally nimble enough to embrace good ideas arriving from any direction, especially from outside the proverbial box.

NASA's workforce, the women and men of storied accomplishments and can-do skills, must embrace change with a passion. Infallibility cannot not be made a precondition of employment in a mission this hard and this urgent. But NASA's every action must be disciplined, professional, and extraordinarily transparent. Budgets must be honored, schedules and performance milestones successfully met, and safety treasured. Such stewardship provides the foundational support for institutional credibility. Such credibility will make NASA an apt trustee for our nation's bold ambitions for human exploration.

Further, preserving credibility requires an unyielding commitment to safety, yet clarity regarding risk. Spaceflight is difficult, hazardous, and confronted by enormous distances, at least in human terms. Despite extensive safety precautions, during its 144 human space missions the United States has lost 17 astronauts. The pursuit of discovery is a risky business, and it will continue to be so for the foreseeable future. Astronauts know this and accept the risk; the American people and its leaders also need to understand and accept that space flight is not easy or routine.

The culture of risk taking is fundamentally different in an entrepreneurial community than in government. To galvanize public support, the government must be candid about the risks associated with space exploration. While the public does not tolerate incompetence or dishonesty, they do accept that risk pervades life itself. If not, we'd never care for the ill – or get into our cars and drive to work or school. First of all, NASA and its partners must implement robust safety precautions. But NASA, its partners, and the public must also acknowledge that our bold resolve to return to the Moon and travel to Mars cannot be drained of all risk.

Finally, the government's credibility as a partner will also hinge on its commitment to reduce market and regulatory risk, and implement meaningful incentives for private sector investment in space ventures. Several financial investors testified with a common metaphor: our government should act like a tenant, rather than a landlord. NASA, they concede, is certainly the anchor tenant in implementing the vision, but the public owns the vision and the three imperatives – sustainability, affordability, and credibility – will require both public and private investment.

> *Our president has introduced a new initiative with renewed emphasis on exploration of our solar system and expansion of the human frontiers. This proposal has substantial merit and promise.*
>
> *The success of that endeavor will be dependent upon overcoming principal concerns of cost and risk. Our economy can certainly afford an effort of this magnitude, but the public must believe that the benefits to society deserve the investment … The rate of progress is proportional to the risk encountered. The public at large may well be more risk-averse than the individuals in our business, but to limit the progress in the name of eliminating risk is no virtue.*
>
> *The success of the endeavor will also be dependent upon the degree to which the aerospace community, all of us – government, industry, and academia – can coalesce their forces and converge on a common goal.*
>
> – Neil Armstrong
> Apollo 11 Commander
> March 11, 2004

E. Outline of What Follows

Our report does not aim to be a researcher's tome or an engineer's blueprint for specific space systems. Nor will it recommend particular missions and methods, which will evolve with fitting granularity as the national journey unfolds. We present, instead, a compact ***architecture for how to implement the space exploration vision***. Our approach is based around eight Findings and fourteen Recommendations, which are, respectively, the basic conclusions and specific advice of the Commission.

We address the components of our implementation architecture in five additional chapters as follow:

Chapter II. Organizing the U.S. Government for Success focuses on core management and investment decisions that the U.S. government should consider to launch and successfully support this journey over multiple decades. This chapter calls for fundamental transformation at NASA, both structural and cultural.

Chapter III. Building a Robust Space Industry makes a case that the exploration vision must, from the outset, include a system of appropriate procurements, prizes, and incentives that will stimulate creation of a robust space industry. This industry should be one that can flourish in support of the vision and of diverse other entrepreneurial objectives.

Chapter IV. Exploration and Science Agenda argues that the vision must be informed by science and nimble enough to evolve as a discovery-driven enterprise.

Chapter V. Inspiring Current and Future Generations urges aggressive, coordinated efforts to engage teachers, our youth, and the innovation economy to train and educate the new generation of explorers who will take us to the Moon, Mars, and beyond.

Chapter VI. Concluding Comments summarizes the challenges and demands that the nation and its leadership will face as we begin the space exploration journey.

Section II

Organizing the U.S. Government for Success

Returning to the Moon and sending humans to Mars will require much more than an incremental extension of mankind's existing experience in space. It is an audacious, yet wholly achievable enterprise demanding many dramatically new ways of doing business, most particularly within the government.

The vision will require incessant innovation, excellent management, and a persistent focus on a series of missions that collectively and iteratively build the body of knowledge needed to explore. This is not one mission, but many. It is not a government program, but a national journey.

Although NASA clearly assumes the lead for our nation, many government agencies will also contribute. Other nations too will be invited to join the journey. Most importantly, success hinges decisively on purely commercial organizations, and on thousands of university researchers, private sector scientists, engineers, and entrepreneurs from around the globe, all committed to the same objective.

This sets a daunting management challenge for government leaders. We have every reason to expect, however, that our government can meet this challenge.

Finding 2

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

A. National Vision

Already the President has done the first, most important, and singularly presidential act: he provided the vision itself. What else is needed?

A project of this complexity, duration, and importance should be supported by the entirety of a President's Executive Branch team. Some agencies have jurisdiction that will impact space activity directly, such as the Departments of Commerce, Defense, Energy, and Transportation. The Departments of Education and Health & Human Services might well coordinate necessary public education and research, or provide peer review skills. Still other agencies can contribute best practices in financial management, procurement tools, or workforce training. The range of federal departments and agencies that can help NASA implement this exploration vision is quite large.

This presents to NASA both opportunity and a management challenge. Interagency engagement that makes use of a White House policy coordination structure will help.

Typically, matters that involve multiple agency interests – or ones that relate to a high national priority – receive such support. Presidents of both parties task White House senior officials to coordinate such interagency decisions, facilitate consensus building, and regularly assess progress toward the Administration's major goals. The National Security Council, the Domestic Policy Council, and other more specialized organizations within the White House routinely perform such functions. The Commission thinks the space exploration enterprise would profit from the existence of such a formal policy management mechanism.

Recommendation 2-1

The Commission recommends the President establish a permanent Space Exploration Steering Council, reporting to the President, with representatives of all appropriate federal agencies, and chaired by the Vice President or such other senior White House executive that the President may designate. The council shall be empowered to develop policies and coordinate work by its agencies to share technologies, facilities, and talent with NASA to support the national space exploration vision.

The Space Exploration Steering Council should be a resource and a tool to assist NASA in its work, not a forum for bureaucratic micromanagement or an opportunity to second-guess routine operational decisions delegated to agency heads. When they work well – and typically such bodies do work well – White House coordination can expedite complex decisions, and improve interagency cooperation. It is, however, also a useful prod for NASA to keep its house in order. At least once annually, the Space Exploration Steering Council should meet with the President along with relevant Cabinet-level and agency principals to assess progress toward the exploration vision.

Not all issues or routine interagency planning work need be lodged with the Space Exploration Steering Council. Of particular importance to the space exploration vision is a strong partnership between NASA and the Department of Defense, where research, technical assistance, and operational assets are often shared. The Commission believes that the role of the existing Partnership Council – wherein NASA, the Air Force, and National Reconnaissance Office coordinate mutual work and interests – should also focus actively on supporting the new vision. The Commission recognizes existing collaborative projects, but these do not carry the priority or commitment commensurate within the new vision. A detailed roadmap for this relationship going forward is needed.

This is equally true as regards many other key agencies that can be expected to support the space exploration vision. The Commission thinks it would be an important early task for the Space Exploration Steering Council to ask each relevant Cabinet Secretary or agency head to work with the NASA Administrator to prepare implementation plans for the Council. Taken together, they should contain specific commitments on how each will appropriately support the national priority for space exploration. The plans should be reviewed and adopted in time to identify any changes that must be incorporated into the federal FY 2006 budget.

Because the role of the private sector is central to the endeavor, the President should create an advisory board that provides an independent source of ongoing advice regarding the government's implementation of the national space exploration mandate. Small enough to facilitate meaningful discussion, this Board should be comprised of individuals deeply experienced in private and public sector management, and qualified on the basis of achievement, independence, and integrity. The

Commission suggests that the President's Foreign Intelligence Advisory Board provides one organizational model for consideration.

Finally, Congressional support for the space exploration vision is crucial. Without Congressional consensus, the vision will be stillborn. Continual, candid, and efficient two-way communication will be a fundamental task for both the Administration and Congress.

B. Transforming NASA

Root-and-branch change must be fully internalized throughout NASA at the outset of this journey – and further adaptations may be necessary as the journey evolves. In some parts of NASA, the necessary changes will be welcomed and will flourish easily. Other parts may oppose any change at all.

It would be wrong to interpret this Commission's focus on implementing change at NASA as a vote of "no confidence." The Commission has every reason to expect that NASA will be given the management tools and structure to make it a superb organization to fit the new mission, one where talent and performance is inferior to no organization, public or private. Indeed, the Commission applauds efforts already undertaken by NASA to improve its efficiency and operations, such as the recently enacted personnel act, and in its accomplishments in the President's Management Agenda.

Finding 3

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

(1) Relationship to the Private Sector. Implementation of the space exploration vision must be built around several core management principles and comprehensively internalized throughout NASA. Most crucial is a significant shift regarding NASA's relations with the private sector.

Recommendation 3-1

The Commission recommends NASA recognize and implement a far larger presence of private industry in space operations with the specific goal of allowing private industry to assume the primary role of providing services to NASA, and most immediately in accessing low-Earth orbit. In NASA decisions, the preferred choice for operational activities must be competitively awarded contracts with private and non-profit organizations and NASA's role must be limited to only those areas where there is irrefutable demonstration that only government can perform the proposed activity.

The Commission believes that commercialization of space should become a primary focus of the vision, and that the creation of a space-based industry will be one of the principal benefits of this journey. One of the challenges we face is to find commercial rewards and incentives in space. Creating these rewards is an indispensable part of making this partnership work in the right way. It will signal a major change in the way NASA deals with the private sector, and the Commission believes that NASA should do all it can to create, nurture, and sustain this new industry. This should include efforts specifically tailored to small, entrepreneurial firms, as well as established larger firms. Each can do things the other cannot. Both are essential contributors.

Today an independent space industry does not really exist. Instead, we have various government-funded space programs and their vendors. Over the next several decades – if the exploration vision is implemented to encourage this – an entirely new set of businesses can emerge that will seek profit in space. This new space industry will reduce the cycle-time for critical technology innovation. It will immeasurably augment NASA's ability to explore the universe.

What is impossible today will, in time, be commonplace. What is inherently governmental today will also change with time, especially if public mission objectives (e.g., to re-supply the International Space Station) are intentionally allowed to intersect and support wholly unrelated commercial opportunities, such as the development of launch technology in support of space tourism.

Over the next several decades – if the exploration vision is implemented to encourage this – an entirely new set of businesses can emerge that will seek profit in space. This new space industry will reduce the cycle-time for critical technology innovation.

We cannot overemphasize the impact a transformed NASA will have on the economy at large, if NASA truly commits itself to this new relationship. The Commission heard repeated and persuasive testimony that NASA could squeeze so much more than it currently does from its taxpayer investment. If it does so, NASA will forge a truly effective engine for innovation and discovery.

To the extent possible, NASA should establish performance-oriented goals and then allow the private sector to compete aggressively to achieve mission objectives. Doing so will allow us to do more scientific work in space sooner, reduce government investment, and make long-term goals more affordable.[1]

The Commission believes that the private sector is willing and capable of providing the initial boost into low-Earth orbit for the payloads associated with the vision. To foster the continued development of this emerging market, the Commission believes that NASA should procure all of its low-Earth orbit launch services competitively on the commercial market. Fortunately, many of the laws and statutes to accomplish this are already on the books. The Commission also realizes that the launch of human crews requires extraordinary care and will likely remain the providence of the government for at least the near-term.

NASA must begin not only to utilize private sector launch enterprises more systematically, its exploration architecture must systematically support private sector capabilities that will make it possible to sustain operations in space. Over time, missions to the Moon, Mars, and beyond will test various methods for finding commercial value in space, including use of *in situ* or space resources. Collecting

1. The Commission thinks the Administration should evaluate the manner and extent to which limited advertising or sponsorships might also provide supplemental revenue to accelerate discovery. It works to fund many other noble pursuits on Earth, such as the Olympics. This issue and other admittedly controversial questions should be explored, as a former member of Congress advised the Commission, with a "yes, if…" mentality rather than with a "no, but" mindset.

and transmitting energy to re-power satellites, mining mineral resources, conducting new materials research, or low gravity manufacturing: the public advanced these and many more ideas to us.

Space resources are useable assets from space that don't have to be brought up from the Earth's deep gravity well. By virtue of already being in space, they have operational and economic value. They include materials and energy – and take different forms on different solar system objects. One of the goals of the vision is to create new capabilities in space, and to answer the question "Can we live off-planet?" Understanding how to use space resources is central to that inquiry.

Perhaps of greatest relevance are resources required by humans to live and work in space. For example, the common H_2O (water) molecule can yield oxygen to breathe, water to drink, and oxygen and hydrogen as propellants. Fortunately, these potential resources exist in some form in abundance at the first two human destinations, the Moon and Mars. Currently, there are many unknowns about the extraction of useful materials and the operations needed to support such activity. These issues will require expertise from both the aerospace and mining industries.

The Commission does not minimize the technical difficulty of this new endeavor; however, because of its importance for future human activity in space, research should be devoted to understanding the problems associated with resource utilization.

NASA's role in this part of the vision should be to conduct research to identify and test techniques needed to produce this material. But the agency should not be in the manufacturing business. Once NASA has pioneered the way and demonstrated the processes to get to these resources and extract and store them, then this new enterprise should be transitioned to the private sector for production.

Establishing the right relationship with the private sector is first a matter of changing the culture at NASA. The Columbia Accident Investigation Board called for pervasive cultural change at NASA as part of its recommendations for return to flight. Implementation of these recommendations is fundamental to NASA's future, and has been recognized as such by NASA's management.

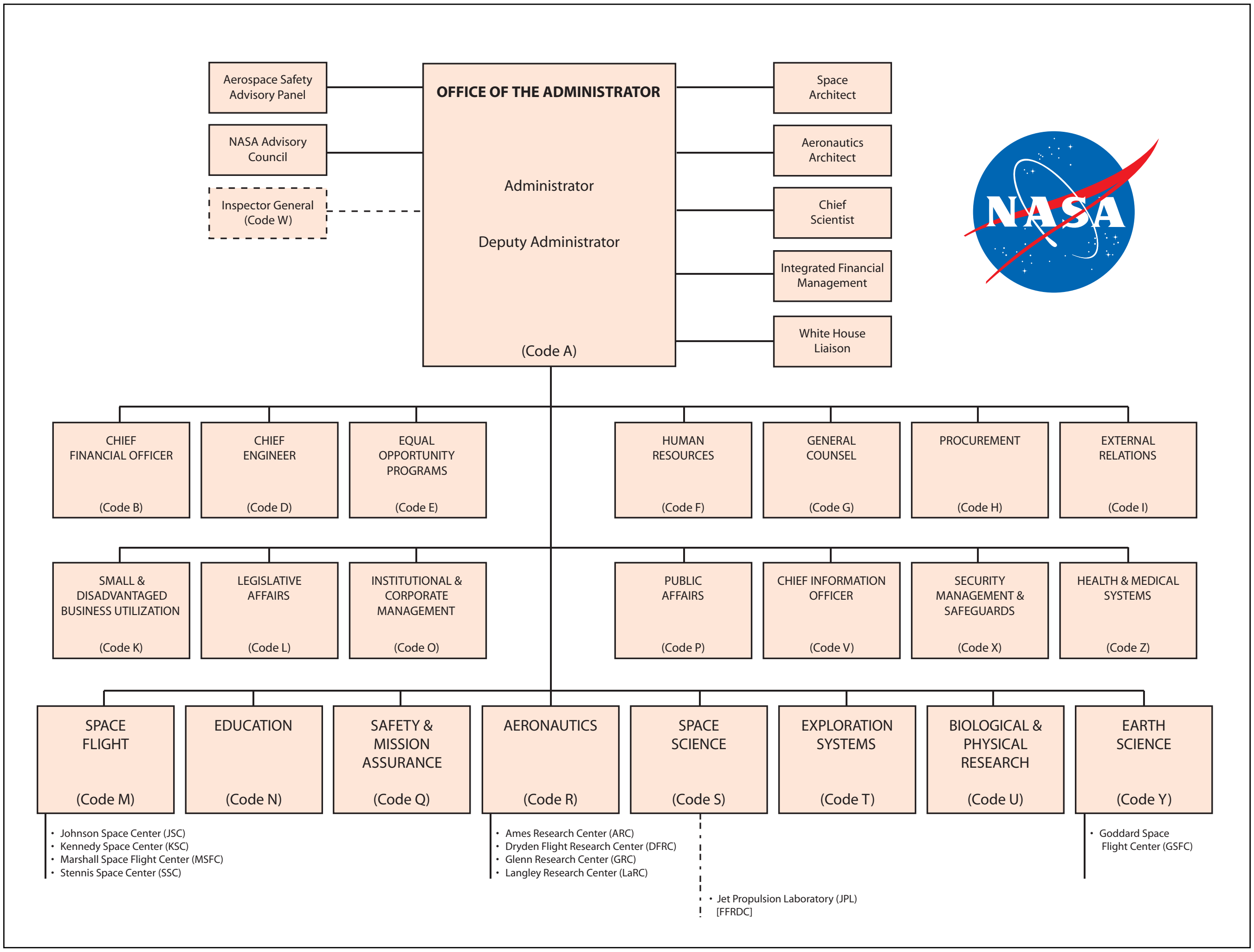
This Commission too calls for fundamental cultural change within NASA. Our focus is, however, a somewhat different, though certainly complementary set of issues: NASA's business culture.

The Commission is convinced that NASA's business culture must be changed to embrace a significantly different role for itself in our space exploration enterprise. NASA needs a much-improved capability both to learn from and partner with a more robust space industry. The new NASA will be frugal and more nimble. Perhaps most importantly, it will be driven by an overarching imperative to do only those things that are inherently governmental, thus not competing with, but encouraging the entrepreneurs who will build a new and robust space industry to support the vision. This is no modest shift.

(2) Organizational Structure. The Commission believes that NASA needs to transform itself into a leaner, more focused agency by developing an organizational structure that recognizes the need for a more integrated approach to science requirements, management, and implementation of

Recommendation 3-2

The Commission recommends NASA be transformed to become more focused and effectively integrated to implement the national space exploration vision, with a structure that affixes clear authority and accountability.



Currently, NASA's organization chart is not wired for success. The first task is to realign the NASA Headquarters organizations to support the long-term vision. There are currently too many mission-focused enterprises and the mission support functions are excessively diffuse. (Source: NASA)

systems development and exploration missions. Currently, NASA's organization chart is not wired for success. Our recommendations cluster in four areas: (a) the Headquarters organization; (b) a proper structure for NASA's Centers; (c) some new organizations to improve independent assessments and risk reduction; and (d) processes and practices that can improve NASA management.

(a) NASA Headquarters. The first task is to realign the NASA Headquarters organizations to support the long-term vision. The mission-focused enterprises should be fewer in number and should include: a consolidated science enterprise that will encompass and prioritize all of NASA's scientific missions; an exploration systems enterprise to manage the exploration vision; space operations to support human and robotic missions; an aeronautics enterprise that supports basic and synergistic aeronautical research; and possibly an education enterprise that inspires and supports the necessary high-tech workforce of tomorrow. Presently mission support functions are excessively diffuse and should, where possible, be consolidated and operate as service organizations that consistently reflect NASA's core values and mission.

Moreover, the Administration has decided to shed some current functions at NASA, transferring some launch vehicle responsibilities to the Department of Defense. Although we make no specific recommendations for further functional divestiture, the Commission strongly believes that, over the multi-decadal course of the Moon to Mars journey, the Administration and Congress ought periodically to do a bottom-up review of whether further functional divestiture is needed. NASA simply cannot afford to spread itself too thin. It must maintain a rigorous focus and the discipline needed to implement the vision.

The Commission is encouraged that NASA's leadership has begun a serious and thoughtful realignment of its assets in support of the national vision. More must be done, and soon. But an excellent start has been made.

Fortunately, NASA's leadership has itself looked deeply into the mirror following the tragic loss of the Orbiter *Columbia*. Under the leadership of its Administrator, NASA further focused its self-assessment in response to the President's exploration vision speech at NASA headquarters. NASA has already taken an essential and promising initial step by creating the Exploration Systems office, which the Commission commends. That act began the process of placing accountability and responsibility for space exploration in a single organization.

The Commission is encouraged that NASA's leadership has begun a serious and thoughtful realignment of its assets in support of the national vision. More must be done, and soon. But an excellent start has been made.

(b) NASA Centers. A second cluster of organizational tasks is to ensure that NASA's ten Centers and their related field facilities are deployed appropriately in supporting the exploration vision. Properly engaged, these facilities and their workforce provide indispensable resources and talent. Centers are also powerful economic engines at the state and local level that should help meet mission objectives and help grow a robust space industry.

As currently organized, NASA's Centers are not optimally configured to carry out the nation's space exploration vision. They have Apollo-era infrastructure that needs substantial modernization. They lack institutional incentives that continuously align performance with the vision's need. Personnel practices have too often ossified, placing insufficient priority on innovation, professional growth, and managerial mobility. In some instances, they support duplicative capabilities that unnecessarily raise NASA's cost to the taxpayers. The Centers, as with the rest of NASA, must also contend with the reality that a large portion of the workforce is now or will soon be eligible for retirement. In short, the Centers must be renewed, empowered, focused, and more effectively leveraged in support of future space exploration and scientific discovery.

The Commission proposes a new model for the NASA Centers. We feel that NASA should transition its Centers through an open, competitive process, to become Federally Funded Research and Development Centers (FFRDCs).

FFRDCs provide a tested, proven management structure in which many of the federal government's most successful and innovative research, laboratory, technical support, and engineering institutions thrive. NASA's Jet Propulsion Lab is currently so configured, as are the Department of Energy's flagship national laboratories. Typically, an FFRDC is managed under long-term federal contract by a university, a non-profit, or for-profit organization selected through open competition.

FFRDCs provide compensation and personnel benefits for their employees that are competitive with the private sector and have personnel flexibility similar to the private sector. They are entrepreneurial in their culture, yet they are prohibited from competing with the private sector to manage production programs. The value of FFRDCs is rooted in their technical competence, flexibility, independence, and objectivity in support of a given federal agency's technical projects. FFRDCs can perform work for non-government organizations so long as this work does not detract from their independence, objectivity, or create a conflict of interest.

The NASA Centers and Field Facilities

Ames Research Center, Moffett Field, California

Dryden Flight Research Center, Edwards, California

Glenn Research Center at Lewis Field, Cleveland, Ohio

Goddard Space Flight Center, Greenbelt, Maryland
- ➢ Independent Verification & Validation Facility, Fairmont, West Virginia
- ➢ Goddard Institute for Space Studies, New York, New York
- ➢ Wallops Flight Facility, Wallops Island, Virginia

Jet Propulsion Laboratory, Pasadena, California

Johnson Space Center, Houston, Texas
- ➢ White Sands Test Facility, White Sands, New Mexico

Kennedy Space Center, Florida

Langley Research Center, Hampton, Virginia

Marshall Space Flight Center, Huntsville, Alabama

Stennis Space Center, Mississippi

This model would work well for NASA Centers, with the exception that some specific governmental functions (such as contracting, launch operations, and flight operations) should remain under direct federal management within given Centers.

(c) New Organizations. The third cluster for organizational change recommends that NASA draw upon certain best practices and successes at other federal agencies to enhance its managerial effectiveness.

Obtaining independent assessments of program schedule, cost, performance, and risks can enhance success and credibility in managing highly technical procurements. Such independent assessments are best accomplished by experienced individuals who have no ongoing reporting relationship to the programs being assessed or to the senior leaders of that program. The Department of Defense has institutionalized

Recommendation 3-3

The Commission recommends that NASA Centers be reconfigured as Federally Funded Research and Development Centers to enable innovation, to work effectively with the private sector, and to stimulate economic development. The Commission recognizes that certain specific functions should remain under federal management within a reconfigured Center.

Recommendation 3-4

The Commission recommends that the Administration and Congress work with NASA to create three new NASA organizations:

- *a technical advisory board that would give the Administrator and NASA leadership independent and responsive advice on technology and risk mitigation plans;*
- *an independent cost estimating organization to ensure cost realism and accuracy; and*
- *a research and technology organization that sponsors high risk/high payoff technology advancement while tolerating periodic failures.*

such an approach with its Defense Science Board. It has found that such reviews often successfully identify technical issues and solutions unanticipated by managers, and improve program performance.

In this regard, the Commission has reviewed the record of the Defense Science Board, and offers it as an apt model for NASA to emulate. The Commission concludes that an independent "space science board" would provide the NASA Administrator and other NASA leaders with valuable advice on technical matters associated with the exploration vision.

Since the 1960s, the Department of Defense has also used an organization called the Cost Analysis Improvement Group (CAIG) for making independent cost estimates of weapon systems. This organization reports to the Office of the Secretary of Defense, thus having no ties to the military departments responsible for the acquisition and operations of weapon systems. Its long duration has allowed the organization to accumulate an enormous amount of data on weapon costs and to develop highly accurate cost estimating procedures. Historical evidence indicates that the CAIG is capable of predicting actual cost within a few percent, and much more accurately than those responsible for weapons development. Although not a technical operation, the CAIG's analytical tools, experience, and accumulation of data has allowed it to identify when a program manager has underestimated the cost or schedule of specific tasks. The Commission believes an independent cost analysis organization would also be valuable to NASA improving credibility, cost estimating, and program execution.

Finally, we suggest that the Administration and Congress create within NASA an organization drawing upon lessons learned from the Defense Advanced Research Projects Agency (DARPA). DARPA is a highly successful organization that is chartered to fund high-risk/high return basic research in support of national defense priorities. The Commission concludes that such an agency within NASA would be extremely useful in addressing the development challenges regarding numerous technologies associated with the vision. In addition, such an organization can be the incubator of cutting-edge technologies and concepts that may not yet have known applications. The Commission believes that the NASA Institute for Advanced Concepts may serve as a nucleus for such an organization.

(d) Management Practices and Processes. The Commission urges that NASA's exploration architecture for the space vision be built upon certain management practices and tools that have been used successfully to implement large-scale procurements and conduct complex operational activity in both the federal government and the private sector.

Recommendation 3-5

The Commission recommends that NASA adopt proven personnel and management reforms to implement the national space exploration vision, to include:

- *use of "system-of-systems" approach;*
- *policies of spiral, evolutionary development;*
- *reliance upon lead systems integrators; and*
- *independent technical and cost assessments.*

For the sake of simplicity, the Commission suggests that NASA's management practices be built around three core concepts: system-of-systems architecture; lead systems integrator procurement; and spiral, evolutionary development. It is difficult to overstate the importance of NASA understanding and effectively using these powerful management processes to guide its long-term stewardship of the national vision.

Implementation of the exploration vision entails stitching together thousands of discrete components and interdependent tasks into a single "system-of-systems." How does the U.S. Secret Service protect the Commander-in-Chief? They employ a system-of-systems. Their mission depends upon the successful integration of numerous assets, techniques, procedures, intelligence systems, and persons all relentlessly focused on the mission of security. So too are the U.S. Coast Guard's Integrated Deepwater System acquisition and the Department of Defense's Future Combat System procurement designed and managed as systems-of-systems. These complex multi-systems are terrifically interdependent, *i.e.*, each system within affects others. The synthesis of very large systems often results in different problems than those presented by the design of a single, but complex, system.

NASA's bold new mission will require careful implementation of a system-of-systems management architecture. It is not the purpose of this report to provide a tutorial on system-of-systems management. Suffice to say that NASA must fully explore and use the long list of available lessons, and fully internalize those lessons to manage what will surely be mankind's most complex technical undertaking.

Increasingly, state and federal governments have also turned to lead systems integrator procurements to accomplish complex assignments. These range from creating the Transportation Security Administration in the wake of the September 11th terrorist attacks, to managing the most complex military procurements.

The lead systems integrator assumes much of the management responsibility for a given program, supporting design trade-offs, selecting contractors to design and manufacture systems, then integrating these into a system-of-systems to meet mission specifications. In the case of U.S. Missile Defense, for example, the integrator is responsible for the overall system of systems architecture, and for integrating the space, air, land, and sea elements of the architecture. The lead systems integrator actually designs and builds some systems or subsystems of these elements, but is primarily focused on integrating the various systems to achieve a coordinated capability.

The Commission strongly advises that NASA build implementation around what may be, over time, a series of lead systems integrator contracts that will deliver major portions of the work that must be done. These procurements must be managed to attract non-aerospace businesses to the exploration endeavor, both large and small firms that are well established and inventors with precious few assets but their genius and drive. To achieve our goals, we will need the best talent the world can offer.

Although the Commission has not tried to prioritize a list of enabling technologies, we have been particularly concerned that NASA pay close attention early to assessing options for a new heavy-lift space launch capability.

Finally, NASA must design an exploration architecture that evolves iteratively, systematically through a series of so-called spiral developments. Technology developed, problems solved, and scientific discoveries made in the initial spirals must all be sequenced to support subsequent work. America will not set out immediately to Mars. The capability to do so will emerge in time, only as part of a planned series of interrelated discoveries and accomplishments.

The key to this concept is to establish realistic, integrated technology development plans that will achieve early performance capabilities and allow new technologies to be "spun" into the program when they are mature enough to do so – thus improving performance and capability in cycles.

The Commission is encouraged that NASA has already elected to apply spiral development to the Crew Exploration Vehicle, and believes this should be the model for the development of the other elements of the vision. This is particularly true for tackling development of enabling technologies, as discussed below.

C. Enabling Technologies

The exploration vision will require significant study, technical work, innovation, and achievement in certain defined technical research areas that we define as "enabling technologies."

As part of our investigations, subsets of the Commission conducted fact-finding trips to the Goddard Space Flight Center, Jet Propulsion Laboratory, Johnson Space Center, Kennedy Space Center, and the Marshall Space Flight Center. In these visits and discussions with headquarters staff, we asked NASA experts to identify and discuss possible clusters of enabling technology. We also pursued this question with staff of the Air Force Research Laboratory and numerous others who testified before the Commission or submitted written statements.

Finding 4

The Commission finds that successful development of identified enabling technologies will be critical to attainment of exploration objectives within reasonable schedules and affordable costs.

There was significant agreement that helped the Commission identify 17 areas for initial focus. Surely others will emerge over time. At this juncture, we identify the following enabling technologies, which are not yet prioritized:

- *Affordable heavy lift capability* – technologies to allow robust affordable access of cargo, particularly to low-Earth orbit.
- *Advanced structures* – extremely lightweight, multi-function structures with modular interfaces, the building-block technology for advanced spacecraft.
- *High acceleration, high life cycle, reusable in-space main engine* – for the crew exploration vehicle.
- *Advanced power and propulsion* – primarily nuclear thermal and nuclear electric, to enable spacecraft and instrument operation and communications, particularly in the outer solar system, where sunlight can no longer be exploited by solar panels.
- *Cryogenic fluid management* – cooling technologies for precision astronomical sensors and advanced spacecraft, as well as propellant storage and transfer in space.
- *Large aperture systems* – for next-generation astronomical telescopes and detectors.
- *Formation flying* – for free-space interferometric applications and near-surface reconnaissance of planetary bodies.
- *High bandwidth communications* – optical and high-frequency microwave systems to enhance data transmission rates.
- *Entry, descent, and landing* – precision targeting and landing on "high-g" and "low-g" planetary bodies.
- *Closed-loop life support and habitability* – Recycling of oxygen, carbon dioxide, and water for long-duration human presence in space.
- *Extravehicular activity systems* – the spacesuit of the future, specifically for productive work on planetary surfaces.
- *Autonomous systems and robotics* – to monitor, maintain, and where possible, repair complex space systems.
- *Scientific data collection/analysis* – lightweight, temperature-tolerant, radiation-hard sensors.
- *Biomedical risk mitigation* – space medicine; remote monitoring, diagnosis and treatment.
- *Transformational spaceport and range technologies* – launch site infrastructure and range capabilities for the crew exploration vehicle and advanced heavy lift vehicles.
- *Automated rendezvous and docking* – for human exploration and robotic sample return missions.
- *Planetary in situ resource utilization* – ultimately enabling us to "cut the cord" with Earth for space logistics.

Recommendation 4-1

The Commission recommends that NASA immediately form special project teams for each enabling technology to:

- *conduct initial assessments of these technologies;*
- *develop a roadmap that leads to mature technologies;*
- *integrate these technologies into the exploration architecture; and*
- *develop a plan for transition of appropriate technologies to the private sector.*

Scoping for the work associated with these enabling technologies should begin now. For most, we do not yet know how to define success. For some, the solutions may be found largely through a proper engagement with the private sector. For others, the task may be dependent upon a knowledge base that is almost wholly found among government researchers. Some of these technologies or associated research may, over time, evolve from primarily governmental to primarily private sector.

The Commission would suggest that each proposed project team be asked report back within roughly six months, so that any budget prioritization can be incorporated into the FY 2006 budget submission. Each initial assessment would: (a) define the relevant issues; (b) survey current knowledge; and (c) draft recommendations for next steps, which should include when and how results must be integrated to the exploration architecture.

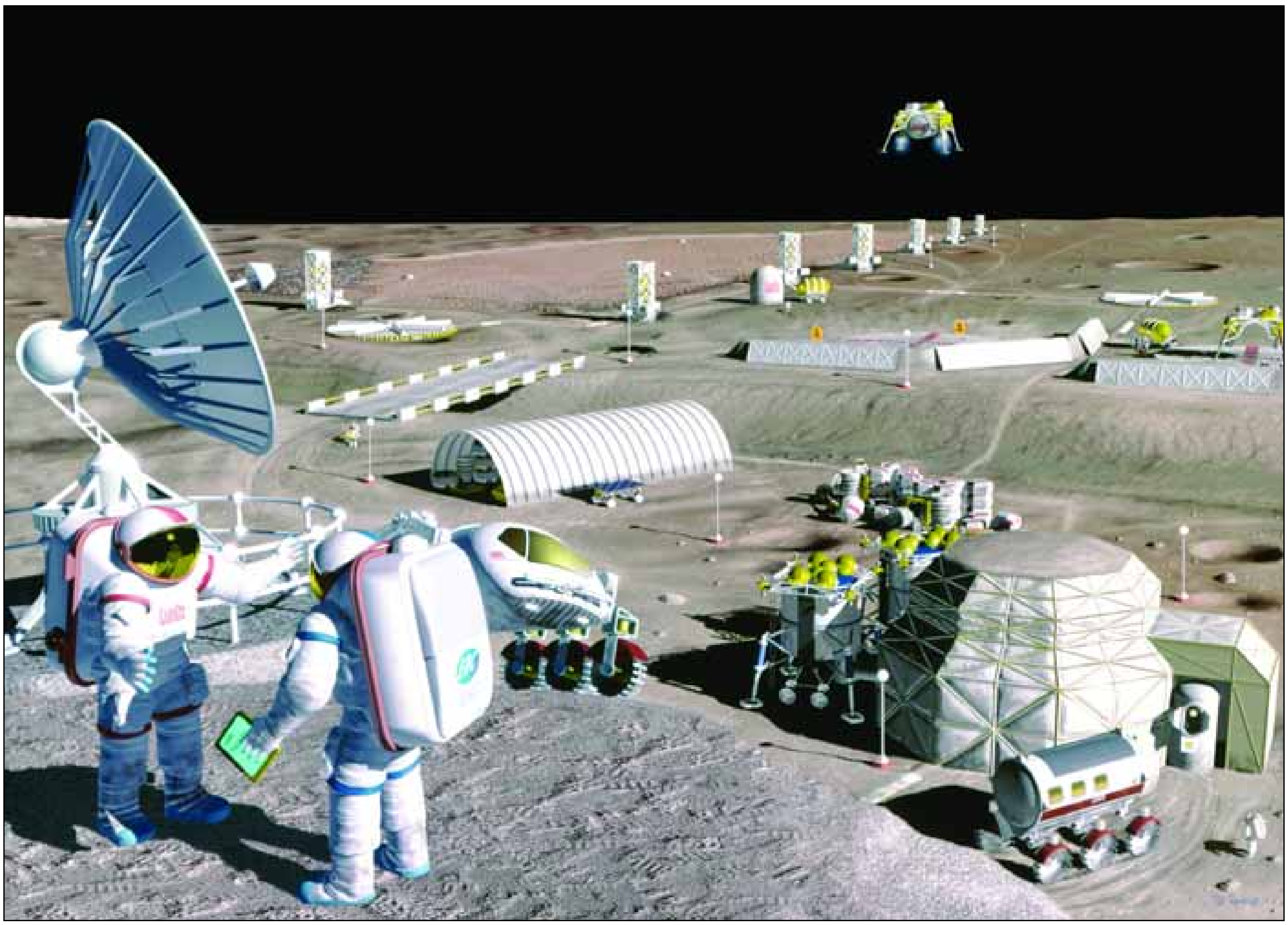
Significant work is already underway at NASA in each of these areas. For example, since announcement of the space exploration vision, NASA has energized an interagency working group on nuclear propulsion that includes the Department of Energy and the Department of Defense. The Commission is suggesting the creation of a single, consolidated evaluation process that can begin to prioritize and inform the exploration architecture.

Although the Commission has not tried to prioritize a list of enabling technologies, we have been particularly concerned that NASA pay close attention early to assessing options for a new heavy-lift space launch capability. Decisions about heavy lift will guide fundamental options about how to design and implement the early stages of the space exploration architecture, and will have long-lasting impacts upon future development costs and capabilities.

One of the most-discussed heavy-lift launch vehicle concepts is based upon using a variety of shuttle-derived components, such as this notional Shuttle-C design. (Source: NASA/John Frassanito & Associates)

Since completion of the Apollo program and the last launch of a Saturn V, the United States has relied on the Space Shuttle for placing large payloads (roughly 55,000 pounds) into low-Earth orbit. Saturn V carried a far greater payload, approximately 250,000 pounds to low-Earth orbit. The heavy-lift variants of the Evolved Expendable Launch Vehicles (EELV) will soon come on-line with a capacity of lifting up to 50,000 pounds into low-Earth orbit or 30,000 pounds into geosynchronous transfer orbit.

The missions to be undertaken as part of the exploration vision will likely require a lift capability beyond today's Space Shuttle and EELVs. There are numerous technologies and sub-technologies that need to be developed, matured, and demonstrated to achieve the desired goals of future heavy-lift launch vehicles. These technologies include: hydrocarbon and hydrogen propellant engine development; lightweight, high-reliability actuation systems; low-cost range tracking systems; durable, lightweight organic, metallic, or composite structures; miniaturized avionics; integrated health monitoring and management systems; and advanced sensors for structural and environmental monitoring. Heavy-lift capability is a critical enabling technology for mission accomplishment and a plan for achieving this capability needs to be developed now.



Just a few miles from the Apollo 17 Taurus Littrow landing site, a lunar mining facility harvests oxygen from the resource-rich volcanic soil of the eastern Mare Serenitatis – one possible space industry. Here a marketing executive describes the high iron, aluminum, magnesium, and titanium content in the processed tailings, which could be used as raw material for a lunar metals production plant. (Source: NASA/Pat Rawlings)

Section III

Building a Robust Space Industry

The vision for space exploration offers the nation and the world a chance to redefine the paradigm of space flight. Our goal is to transform space exploration from a small, experimental research program, largely performed under the auspices of government into a fully integrated sector of American life, involving government, commercial, educational, and industrial players.

Although an *aerospace* industry already exists and provides commercial launch services worldwide, its principal business currently consists mostly of corporate entities that perform contract work for various government agencies. The Commission uses the term *space industry* to refer to something much broader – a true space industry would consist of a variety of contributors, each vigorously pursuing their own diverse agendas, not tied to or dependent upon government contracts, but not excluding those activities either. Achieving such a state requires the breaking down of barriers to commercial and entrepreneurial activities in space, as well as a cultural shift towards encouraging and incentivizing more private sector business in space. Such a change in both perspective and posture is essential if we are to develop a broad-based, societal change in space business.

Finding 5

The Commission finds that sustaining the long-term exploration of the solar system requires a robust space industry that will contribute to national economic growth, produce new products through the creation of new knowledge, and lead the world in invention and innovation. This space industry will become a national treasure.

A. Technology Transfer

In addition to the innovation directly produced by NASA and the government, many innovative technologies are developed annually by American businesses. Many of these breakthroughs occur in fields unrelated to space, yet potentially have direct application to many aspects of, and problems attendant to, space flight. To be certain that we are always taking advantage of the best possible technology in a task as arduous as space exploration, we must find mechanisms to assure that good technical ideas that spring from outside the government find their way into the architectures and systems of the new space vision. If the vision for exploration is to succeed in an affordable, credible, and sustainable way, it must access as much of this private sector technology as possible.

We suggest that NASA examine the creation of an organization drawing upon lessons learned from the Central Intelligence Agency's In-Q-Tel. This company searched the private sector widely, looking for useful technologies that might have important national security applications. The

Commission concludes that such an entity within NASA would be extremely useful in addressing the more demanding needs of some enabling technologies. In addition, such an organization can be the incubator of cutting-edge technologies and concepts that may not yet have known applications.

Recommendation 5-1

The Commission recommends NASA aggressively use its contractual authority to reach broadly into the commercial and nonprofit communities to bring the best ideas, technologies, and management tools into the accomplishment of exploration goals.

B. Encouraging Commercial Activities

Although many companies exist and more are emerging in the field of space, an increase in both the number and variety of such businesses would vastly increase the processes and materials available for space exploration. The private sector will continue to push the envelope to succeed competitively in the space field. It is the stated policy of the act creating and enabling NASA that it encourage and nurture private sector space. The Commission heard testimony on both positive incentives and potential bottlenecks encountered by the private sector as they attempt to exploit these commercial opportunities.

A space industry capable of contributing to economic growth, producing new products through the creation of new knowledge and leading the world in invention and innovation, will be a national treasure. Such an industry will rely upon proven players with aerospace capabilities, but increasingly should encourage entrepreneurial activity.

Prizes. The Commission heard testimony from a variety of sources commenting on the value of prizes for the achievement of technology breakthroughs. Examples of the success of such an approach include the Orteig Prize, collected by Charles Lindbergh for his solo flight to Europe, and the current X-Prize for human suborbital flight. It is estimated that over $400 million has been invested in developing technology by the X-Prize competitors that will vie for a $10 million prize – a 40 to 1 payoff for technology.

A space industry capable of contributing to economic growth, producing new products through the creation of new knowledge and leading the world in invention and innovation, will be a national treasure. Such an industry will rely upon proven players with aerospace capabilities, but increasingly should encourage entrepreneurial activity.

The Commission strongly supports the Centennial Challenge program recently established by NASA. This program provides up to $50 million in any given fiscal year for the payment of cash prizes for advancement of space or aeronautical technologies, with no single prize in excess of $10 million without the approval of the NASA Administrator. The focus of cash prizes should be on maturing the enabling technologies associated with the vision. NASA should expand its Centennial prize program to encourage entrepreneurs and risk-takers to undertake major space missions.

Given the complexity and challenges of the new vision, the Commission suggests that a more substantial prize might be appropriate to accelerate the development of enabling technologies. As an example of a particularly challenging prize concept, $100 million to $1 billion could be offered to the first organization to place humans on the Moon and sustain them for a fixed period before they return to Earth. The Commission suggests that more substantial prize programs be considered and, if found appropriate, NASA should work with the Congress to develop how the funding for such a prize would be provided.

Tax Incentives. A time-honored way for government to encourage desired behavior is through the creation of incentives in the tax laws. In this case, an increase in private sector involvement in space can be stimulated through the provision of tax incentives to companies that desire to invest in space or space technology. As an example, the tax law could be changed to make profits from space investment tax free until they reach some pre-determined multiple (e.g., five times) of the original amount of the investment. A historical precedent to such an effort was the use of federal airmail subsidies to help create a private airline industry before World War II. In a like manner, corporate taxes could be credited or expenses deducted for the creation of a private space transportation system, each tax incentive keyed to a specific technical milestone. Creation of tax incentives can potentially create large amounts of investment and hence, technical progress, all at very little expense or risk to the government.

Regulatory Relief. Government regulation of the nascent private sector space industry is ongoing and will be necessary in the future, but it is important to ensure that this industry not become overregulated. A key issue in the private space flight business is liability. There is a pressing need for a change in liability laws to set a reasonable standard for implied consent. People throughout society do dangerous things for fun and profit; it is not reasonable to impose governmental risk standards on people who are willing and eager to undertake dangerous or hazardous activities. In addition, numerous laws covering occupational safety and environmental concerns should be reviewed carefully to make sure that the government is not burdening new space industry unduly with irrelevant or unobtainable compliance requirements.

Property Rights in Space. The United States is signatory to many international treaties, some of which address aspects of property ownership in space. The most relevant treaty is the 1967 UN Treaty on the Peaceful Uses of Outer Space (the "Space Treaty"), which prohibits claims of national sovereignty on any extraterrestrial body. Additionally, the so-called "Moon Treaty" of 1979 prohibits any private ownership of the Moon or any parts of it. The United States is a signatory to the 1967 Space Treaty; it has not ratified the 1979 Moon Treaty, but at the same time, has not challenged its basic premises or assumptions.

Recommendation 5-2

The Commission recommends that Congress increase the potential for commercial opportunities related to the national space exploration vision by providing incentives for entrepreneurial investment in space, by creating significant monetary prizes for the accomplishment of space missions and/or technology developments and by assuring appropriate property rights for those who seek to develop space resources and infrastructure.

Because of this treaty regime, the legal status of a hypothetical private company engaged in making products from space resources is uncertain. Potentially, this uncertainty could strangle a nascent space-based industry in its cradle; no company will invest millions of dollars in developing a product to which their legal claim is uncertain. The issue of private property rights in space is a complex one involving national and international legal issues. However, it is imperative that these issues be recognized and addressed at an early stage in the implementation of the vision, otherwise there will be little significant private sector activity associated with the development of space resources, one of our key goals.

C. International Participation

The United States space program has been international since its origins. Starting with the establishment of global ground-tracking stations through the flight of foreign experiments on space science missions, international participation has been thriving. The Apollo/Soyuz was one of the first high-profile international ventures in human space flight, there are international participants on our robotic missions, and we have non-U.S. crew members on the Space Shuttle and the International Space Station (ISS). Such efforts will continue. What additional international arrangements should we undertake specifically oriented toward the vision?

The vision provides the opportunity for significant participation by international partners. They bring resources and expertise, government-to-government commitments contribute to stability and sustainability, and partnerships contribute to constructive dialog between nations. It is hard to envision a national space program based on exploration solely by the United States or any future human spaceflight mission that would be flown only by Americans.

Finding 6

The Commission finds that international talents and technologies will be of significant value in successfully implementing the space exploration vision, and tapping into the global marketplace is consistent with our core value of using private sector resources to meet mission goals.

The Commission heard testimony from potential international partners indicating that they want to participate in the accomplishment of the vision but they are uncertain about the most effective means to do so. They noted, however, that continued American participation in the ISS is important to determining future international participation beyond. ISS is the first step in human exploration, but to reach its full potential the crew size must be expanded beyond current levels.

How our international partners will participate in the vision will depend on the specifics of the architecture that will be established by the United States and the value potential partners bring to the elements of the mission. Prior to entering into government-to-government agreements, the United States must first determine its own requirements, expectations, milestones, and risks. It must also determine what part of its national industrial base it must protect and what technologies it is prepared to transfer to the international partners.

After establishing the vision architecture and determining what the United States is willing to cede, the Commission suggests two possible approaches for international participation:

- Participants bring their own independently operated, but goal-associated, missions as contributions to a subset of mission goals (e.g., a robotic mission that satisfies some of the knowledge or operational goals of a particular architecture).

➢ Participants provide components to an integrated mission that are competed or provided on a “best value” basis and selected by a lead systems integrator, taking into account cost, schedule, and performance risk.

The Department of Defense’s Joint Strike Fighter (JSF) program offers a possible model for international cooperation. The benefits from this cooperation include synergy, financial support, economies of scale, and goodwill generated from the cooperating partners. The program developed an approach that effectively accommodated the interests of the Department of Defense and the JSF program, U.S. industry and the program contractors and sub-contractors, and foreign partners. Early buy-in by foreign governments to encourage full participation throughout the program’s development and production stages was essential. The JSF international strategy was well coordinated within the U.S. government, gaining full support from other agencies and the Congress before implementation. The JSF management approach allowed foreign partners to influence the development and production process to varying degrees based on the extent of their investment, but control of key decisions remained with program authorities in the United States

Recommendation 6-1

The Commission recommends that NASA pursue international partnerships based upon an architecture that would encourage global investment in support of the vision.

Joint Strike Fighter Model

The JSF (F-35) is under development by the Department of Defense to replace the aging F-16s, F/A-18s, F-14s, and AV-8B aircraft. It is an international program consisting of nine partner nations—the United States, United Kingdom, Italy, Netherlands, Denmark, Norway, Turkey, Canada, and Australia. Each partner nation contributes a specified amount of money directly in support of the development and participates in aspects of program management in accordance with government-to-government agreements. The prime contractor and system integrator conduct competitions for components of the development aircraft, giving preference to the partner nation’s industries, and select the winner of the competition on a best value basis. The decision to include an international partner’s proposed component or work content takes into account the cost, schedule, performance, and future political risk. The program also uses an accelerated process for the approval of export licenses. There is no guarantee of any partner nation recouping its investment and there is no offset arrangement. However, economic analyses indicate that all nations are likely to achieve a high rate-of-return based upon the aircraft development and future production.

Section IV

Exploration and Science Agenda

A. Science Research Agenda

Science has held a key position in America's space program since its inception nearly 50 years ago and remains an integral reason for exploring space. Science and exploration are synergistic: science is the attempt to explain nature, while exploration is the establishment and pushing back of a frontier. New frontiers reveal new and unexpected natural phenomena, for which science is called upon to offer explanations.

Finding 7

The Commission finds implementing the space exploration vision will be enabled by scientific knowledge, and will enable compelling scientific opportunities to study Earth and its environs, the solar system, other planetary systems, and the universe.

Science in the space exploration vision is both *enabling* and *enabled*. The ability to create new capability for humans and machines beyond low-Earth orbit will require scientific and technological advances. This includes research to develop the means for precision landing, formation flying, and surface mobility; to understand how the resources of the Moon, Mars, and other bodies can be used to access planetary surfaces and locations in free space, and to operate effectively once there; and to discover and characterize landing sites with the optimal combination of safety, resource accessibility and scientific return. This *enabling science* will be required to plan architectures and derive requirements for robotic and human missions.

Once situated in a location of interest, new science will then be *enabled*. By virtue of a newly established virtual or human presence on or near these objects, we will have vantage points to study the processes that shaped the planets and the history of the universe. These studies, in turn, will also be enabling, by offering new perspectives on the possibilities of creating additional, extended capabilities for science and exploration. Thus, science is an integral part of the space exploration vision, informing and being informed by the ongoing exploration of space. The improved capabilities that will create new opportunities for scientific discovery will derive from the development of enabling technologies and the optimal use of machines and humans in scientific exploration.

In the past, NASA's space and Earth science programs have had a successful record of scientific accomplishment due to peer review-based evaluation processes in the selection of research and space-based mission investigations. These programs have also benefited from broad input from the scientific community in the form of long-range strategic planning to prioritize science objectives.

We recognize these efforts for their seminal contributions to past success, but note that current roadmaps and strategic priorities have not had the opportunity to factor in new opportunities that will be enabled by the space exploration vision. We believe that the various NASA scientific communities should now revisit priorities and plans to consider how they might be adjusted to take advantage of emerging opportunities. To be compatible with exploration architectures and funding profiles, future science plans should have flexible time lines for implementation.

The Commission anticipates that a diverse suite of exploration-based scientific endeavors will emerge from this activity, ranging from the origin and evolution of the universe, to the formation and evolution of the solar system and planetary systems around other stars, to the search for life and the prospects for habitability of humans beyond Earth. An exciting science research agenda can be organized around the following broad themes:

- **Origins** – the beginnings of the universe, our solar system, other planetary systems, and life.
- **Evolution** – how the components of the universe have changed with time, including the physical, chemical, and biological processes that have affected it, and the sequences of major events.
- **Fate** – what the lessons of galactic, stellar, and planetary history tell about the future and our place in the universe.

Examples of richly important scientific questions that could be pursued within these research themes are listed in the Sidebar.

Given the scope of potentially outstanding science, both in directions currently conceived and those not yet envisioned, wide involvement by the science community should be sought for developing a sensible rationale and strategy. We suggest that NASA's new Exploration Systems organization seek independent scientific advice on their exploration architectures to ensure that maximum use is made of scientific knowledge relevant to new capabilities. The scientific community should give serious thought to the optimal balance of using robots and humans to maximize the breadth of scientific discovery given available and emerging technologies and funding levels. In particular, new attention should be given to the question of how to use humans and robots together to synergistically accomplish scientific and exploration goals. We urge the scientific community to be proactive in providing input to the Exploration Systems organization on scientific advances and advanced technologies that would enhance the scientific component of exploration goals.

Finally, while favoring an inclusive future science agenda for the nation, we recognize that attempts to implement a sweeping program consisting of even the most meritorious science could potentially defocus the vision to the detriment of all science. If it is determined that the inclusion of specific highly regarded science programs hampers the implementation of the vision, then such programs, along with their attendant budgets, should be transferred to another government agency or organization that could capably implement them.

Recommendation 7-1

The Commission recommends that NASA seeks routine input from the scientific community on exploration architectures to ensure that maximum use is made of existing assets and emerging capabilities.

A Notional Science Research Agenda

Origins

- The Big Bang, the structure and composition of the universe including the formation of galaxies and the origin of dark matter and dark energy.
- Nebular composition and evolution – gravitational collapse and stellar ignition.
- Formation of our solar system and other planetary systems; clues to the origin of the solar system found in meteorites, cosmic dust, asteroids, comets, Kuiper Belt Objects, and samples of planetary surfaces.
- Pre-biotic solar system organic chemistry – locations, histories, and processes; emergence of life on Earth; interplay between geological and astronomical processes.

Evolution

- The Universe – processes that influence and produce large-scale structure, from sub-nuclear to galactic scales.
- Stellar Evolution – nucleosynthesis and evolutionary sequences, including the influence of particles and fields on the space environment.
- Planetary Evolution – the roles of impact, volcanism, tectonics, and orbital or rotational dynamics in shaping planetary surfaces; structure of planetary interiors.
- Comparative Planetology – study of Earth as a terrestrial planet; divergence of evolutionary paths of Earth, Venus, and Mars; comparisons of giant planets and extrasolar planets.
- Atmospheres – early evolution and interaction with hydrospheres; long-term changes and stability.
- Search for Habitable Environments – identification and characterization of environments potentially suitable for the past existence and present sustenance of biogenic activity.

Fate

- Biology of species in space – micro- and fractional gravity, long-term effects of exposure to variable gravity; radiation; avoidance and mitigation strategies.
- Impact Threat – cataloguing and classification of near-Earth objects; estimation of the recent impact flux and its variations; flux variation with position in solar system; hazard avoidance and mitigation.
- Natural hazard assessment – Advanced space-based characterization of meteorological, oceanic, and solid Earth natural hazards to diminish consequences and advance toward predictive capability.
- Temporal variations in solar output – monitoring and interpretation of space weather as relevant to consequence and predictability.
- Climate change – assessment of recent climatic variations; solar controls on climate change; quantitative modeling and testing of the greenhouse effect; and possible effects on planets and life.
- Long-term variations of solar system environment – galactic rotation and secular variations; local supernovae.

Recommendation 7-2

The Commission recommends that NASA ask the National Academy of Sciences to engage its constituent scientific community in a re-evaluation of priorities to exploit opportunities created by the space exploration vision. In particular, the community should consider how machines and humans, used separately and in combination, can maximize scientific returns.

B. Criteria For the Selection of Future Destinations

The initial destinations defined in the space exploration vision are appropriate and significant targets for future investigation. Returning to the Moon with a robotic and human presence will permit a global reconnaissance of resource potential, will provide humans with much-needed experience operating and exploring on a terrestrial surface other than Earth's, and will undoubtedly lead to scientific discovery. A robotic mission to return rock and soil samples from the surface of Mars will, in addition to providing material from a known location for analysis in the best terrestrial laboratories, demonstrate many of the major technological elements required for an eventual human Mars mission. Orbital telecommunications experiments at both the Moon and Mars will significantly improve communication and data transfer, greatly enhancing scientific returns and operational capabilities of missions to those planets.

As additional skills, capabilities, and operational experience are developed for working in space and on the surface of the Moon and Mars with machines and people, new destinations will beckon. For example, advanced communications demonstrated in the inner solar system will provide the foundation for extending that capability to deeper space. Maturation of nuclear power technologies currently under development as part of NASA's Project Prometheus will greatly enhance the exploration of targets in the outer solar system and elsewhere. And advances in materials, optics, and radiation-hard components will allow construction and deployment of advanced astronomical and solar telescopes in cislunar space and beyond.

In addition, scientific discoveries from ongoing exploration will undoubtedly provide tantalizing targets for future exploration. These could be of economic value, for example, discovery of a significant resource in space. They could be of security interest, for example, the discovery of an asteroid on a collision course with Earth. Or they could be largely of scientific value, for example, discovery of evidence for past or present life on Mars or Europa, or an especially interesting Earth-like planet around a neighboring star. In each case, the exploration program would evolve in response to a discovery made during our near-term space exploration activities.

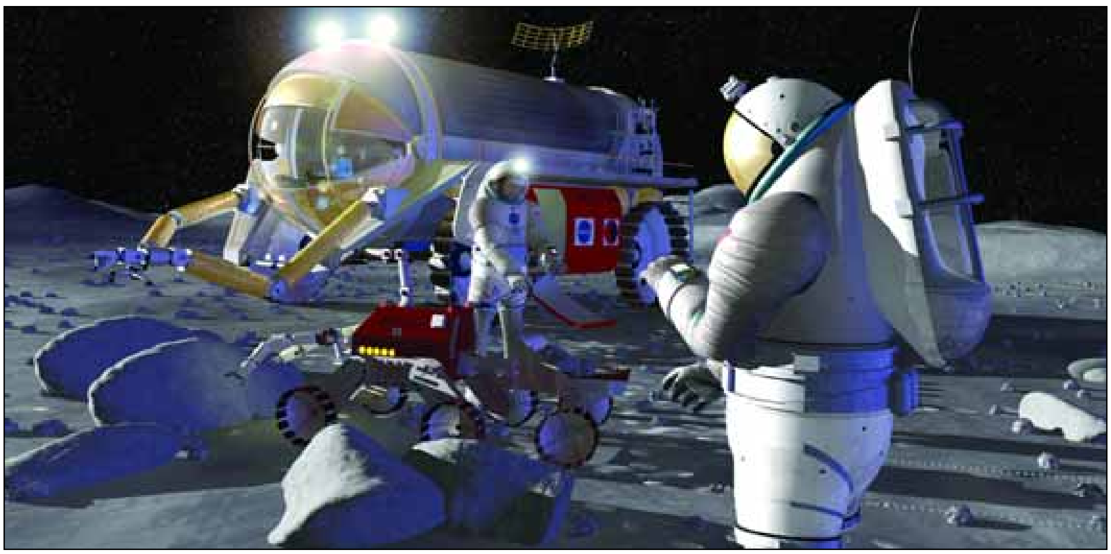
Thus, at present, it is premature to recommend additional specific targets of opportunity. However, the Commission supports a "discovery driven" criterion for decisions on future destinations, as successfully implemented by the NASA Mars Exploration Program. In such an approach, discoveries in early missions combined with:

- ➢ realistic assessment of funding levels,
- ➢ technical readiness level of enabling technologies,
- ➢ scientific evaluation of destinations of interest,
- ➢ resource locations and states, and
- ➢ emerging capabilities and access

will collectively form the basis for extending the present exploration roadmap. This discovery driven program argues for supporting a sensible and affordable mix of space-based fundamental research that extends from dark energy to solar system science, because the history of discovery has shown that one never knows where the next transformative breakthrough will occur.

Recommendation 7-3

The Commission recommends a discovery-based criterion to select destinations beyond the Moon and Mars that also considers affordability, technical maturity, scientific importance, and emerging capabilities including access to in-situ space resources.



Artist concepts of operations on the surface of the Moon (above) and Mars (below). (Source: NASA/John Frassanito & Associates)

Section V

Inspiring Current and Future Generations

Finding 8

The Commission finds that the space exploration vision offers an extraordinary opportunity to stimulate mathematics, science, and engineering excellence for America's students and teachers – and to engage the public in a journey that will shape the course of human destiny.

Space exploration captures the imaginations of America's children and adults. The challenge before us is to leverage the journey to the space frontier to engage learners of all ages and interests. In addition, we must focus on training the workforce needed for the success of the long-term exploration program. The education community, working with NASA, must aggressively educate and train a new generation of explorers – there is perhaps no greater imperative for ensuring successful and sustainable space exploration by this nation.[1]

Extensive anecdotal evidence obtained during Commission fact-finding indicates that many people who grew up during the Apollo era – because they were inspired by the quest to send humans to the Moon – were attracted toward mathematics, science, or engineering. The influence of Apollo on the decision to pursue technical training was as much in evidence among individuals who went on to work in all manner of tech-sector jobs as for those who became involved professionally with the space program.

More recently however, according to the American Institute of Aeronautics and Astronautics (AIAA), industry CEO's have noted the lack of incoming science and technology students – and the fact that the majority of those students are foreign, and many return to their own countries. Although industry leaders are working to bring young, qualified engineers and scientists into their companies, students are often wary of the peaks and valleys in aerospace careers.

Industry leaders must be proactive in sponsoring high school and college courses, offering education incentives, such as scholarships and internships, visiting schools as role models, and providing jobs. Active involvement from industry will provide some of the incentives that are badly needed to persuade students that there are, indeed, fine career opportunities for those who have math, science, and engineering as their core skill set.

1. The workforce required for the United States to prosper as a nation is not being trained adequately. Our current level of achievement in science and technology relative to other countries places America at risk economically and from a national security perspective. Phase III of the 2001 Hart-Rudman Commission report "Road Map for National Security: Imperative for Change" warned that the failure of math and science education was the second largest national security threat facing America.

A. Formal Education Opportunities

The Commission applauds the recent focus on education at NASA, as evidenced by its mission statement: "… to inspire the next generation of explorers … as only NASA can," and the extensive education initiatives of the NASA Education Enterprise. The agency is in a unique position to engage young people in their studies through the excitement of space exploration. NASA's current efforts in formal education are generally successful but could benefit from consolidation of implementation and expansion of effort – especially in the training of current and future teachers.

To maximize the impact of space-related programs in education, NASA should enlist the cooperation of the Department of Education and the National Science Foundation – the two other federal government agencies that have "education" in their charter. These agencies should work together with state and local political leaders to infuse the excitement associated with exploring space into science, math, and technology education programs across the country. They should collectively establish a more aggressive approach for encouraging youth to enter math, science, and engineering professions.

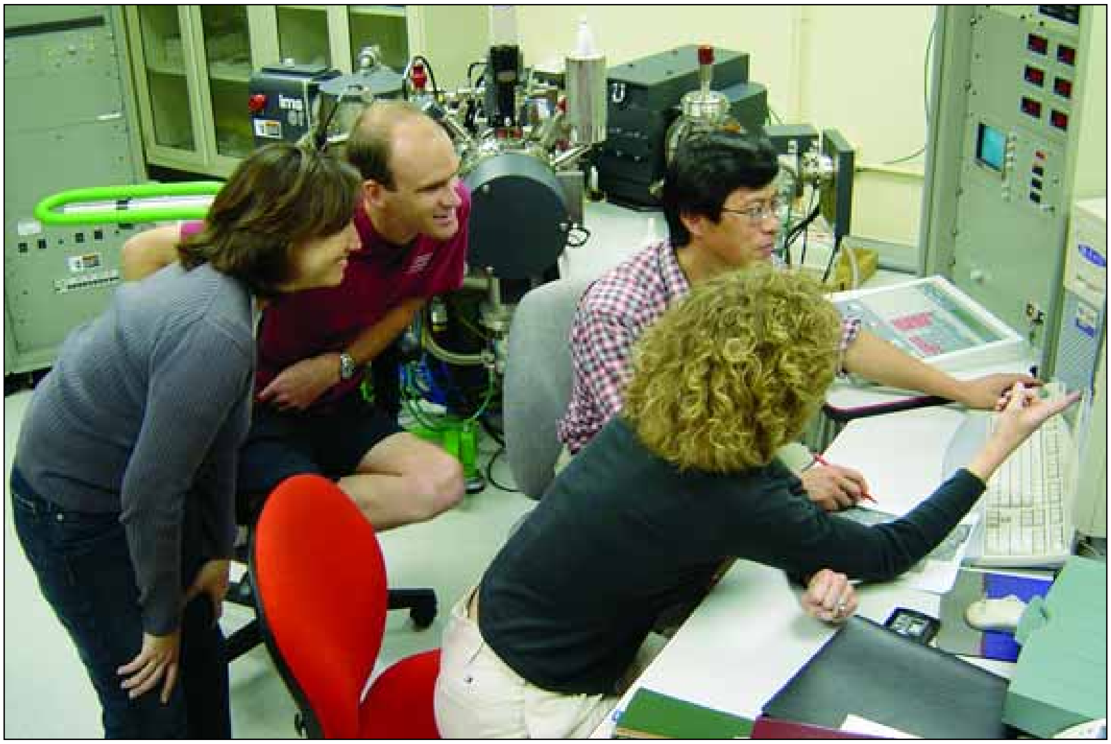
The Commission believes the greatest impact will come from expanding programs to train teachers of science, mathematics, and technology. Future efforts should include in-service active teachers and pre-service teachers, i.e., those who are still in training in university and college programs. Such efforts should focus on providing engaging, state-of-the-art content aligned with existing national science and technology education standards, and emphasize approaches that allow students to experience first-hand the thrill of discovery and innovation.

The Commission believes the greatest impact will come from expanding programs to train teachers of science, mathematics, and technology. Future efforts should include in-service active teachers and pre-service teachers, i.e., those who are still in training in university and college programs.

In addition to enhanced interagency cooperation within the government, the Commission believes that expanded formal K-12 education efforts by industry, universities, and professional associations are needed, and that NASA should strive to integrate its educational efforts with those of these other interested stakeholders. In order for the vision to be as inclusive as possible, education programs need to target and recruit under-represented populations in the fields of math, science, and engineering, particularly those who represent America's emergent demographic. These educational activities contribute directly to the future prosperity of our nation. Everyone involved in exploring space today can make a difference for tomorrow by using the excitement of space exploration to engage the broadest possible cross section of America's children in learning math, science, and engineering.

B. New University Partnerships to Train the Next Generation of Explorers

The Commission suggests that NASA use strategic investments to engage universities in training the workforce capable of taking us on the exploration journey. From astronauts to systems engineers to space scientists, a workforce of great technical skill in their chosen disciplines will be required to implement the system of systems that will accomplish the space exploration vision. However, given the breadth and operational complexities presented by the vision, this next generation workforce will need significant inter-disciplinary experience as well.



One of the benefits of the new vision is to ignite the enthusiam of students to study science and technology. (Source: Laurie Leshin)

At present, there are insufficient methods for students to acquire hands-on experience in the scientific and technical disciplines necessary for space commerce and exploration. Therefore, a new alliance between NASA and universities should be formed. This alliance will provide hands-on training to future space scientists and engineers and produce the next generation workforce required to implement the space exploration vision. NASA and interested universities should work together to create a “virtual”

Recommendation 8-1

The Commission recommends the Space Exploration Steering Council work with America’s education community and state and local political leaders to produce an action plan that leverages the exploration vision in support of the nation’s commitment to improve math, science, and engineering education. The action plan should:

- *increase the priority on teacher training;*
- *provide for better integration of existing math, science, and engineering education initiatives across governments, industries, and professional organizations; and*
- *explore options to create a university-based “virtual space academy” for training the next generation technical work force.*

space academy, the goals of which are: 1) to provide tangible experiences that prepare students for a future in a space-related field, and 2) to bridge the divide between engineering and science training.

The space academy would be funded by NASA, but would take advantage of the "bricks and mortar" as well as intellectual infrastructure already in place in America's universities, allowing both a rapid start to the program and for it to be infused throughout the nation's higher education system. The program would consist of university-based science and engineering experiments to train young scientists and engineers, and summer internships. The experiments would be designed to provide senior undergraduate and/or graduate-level experience for integrated engineering/science teams that teach systems engineering and science/engineering integration through conceptual designs relevant to both robotic and human space missions. Through the space academy program, students would develop projects with science and exploration objectives and engineering implementation, culminating in a mission design. By participating in academy programs, affiliated universities would develop curricula and facilities and produce a workforce imbued with state-of-the-art capabilities.

The space academy program could consist of one-year courses with NASA as content advisor. Individual academic institutions would be tasked to decide how the program could fit within their existing program, but the Commission suggests that the courses could constitute a senior design project or a component of a first year master's degree in engineering or science. Once established, the university-based program could be expanded so that participants spend one or more summers at NASA Centers, with industry partners, or at another academic institution, dividing time between a group project and an internship. Completion of the year-long course and summer program would yield a space academy certificate and serve as a credential, but any degree would be granted by the participant's home institution. Many NASA Centers currently implement successful educational programs that could be adapted to the space academy program, but it is expected that the content would be driven by a shared vision – between NASA and participating institutions – of the skills needed to train future space scientists and engineers.

C. Public Engagement

The entire nation, indeed the world, will be watching as we explore new frontiers and answer profound questions on our journey into space. In fact, public participation is critical to sustaining the space exploration vision. The American people – the taxpayers who pay the bill – must assert ownership of the space program that transcends politics and the political environment.

Based on the testimony of witnesses involved in education, outreach, and the media – as well as on public comments received – the Commission believes a new model is needed to expand the role of space exploration in our culture. Working together, the White House, NASA, industry, and professional organizations can forge a new model for public engagement built on grass roots support. Such support requires sustainable, systematic, effective marketing and communication programs, employs professionals who are trained in the art and science of communication, and uses new, and even novel means for communicating with the public about space.

Recommendation 8-2

The Commission recommends that industry, professional organizations, and the media engage the public in understanding why space exploration is vital to our scientific, economic, and security interests.

The unwavering support of key groups is needed to bring the "earthly" benefits of space exploration to the attention of the broader public. Recently, 13 leading space advocacy and aerospace industry groups joined forces for the first time to promote the space exploration vision and to communicate how the vision advances our scientific, economic, and security interests. More of this type of activity must take place – it's time to connect chambers of commerce, labor unions, school boards, and

Knock Our Socks Off

I am of the Apollo Generation, that lucky group of kids old enough to have experienced the Moon landings, but young enough to not have been distracted by the issues of the adult world.

I was nine years old when Neil and Buzz first walked on the Moon, and I could not get enough!

... One hundred and fifty years ago, if President Lincoln had formed this board, you might have been called "The Commission on Iowa, Colorado and Beyond." And you would have faced the Very Same Questions!

> "Can we afford to explore the West?"
> "Isn't it dangerous out there?"
> "Shouldn't we solve the problems of the East Coast first?"

And maybe even, "Is there life in California?"

But one hundred and fifty years ago, we could have gathered at this very spot, looked down the hill across the waving grass, at the sparkling San Francisco Bay, and, sailing through the Golden Gate (without the bridge) we would have seen schooners and clipper ships by the Score.

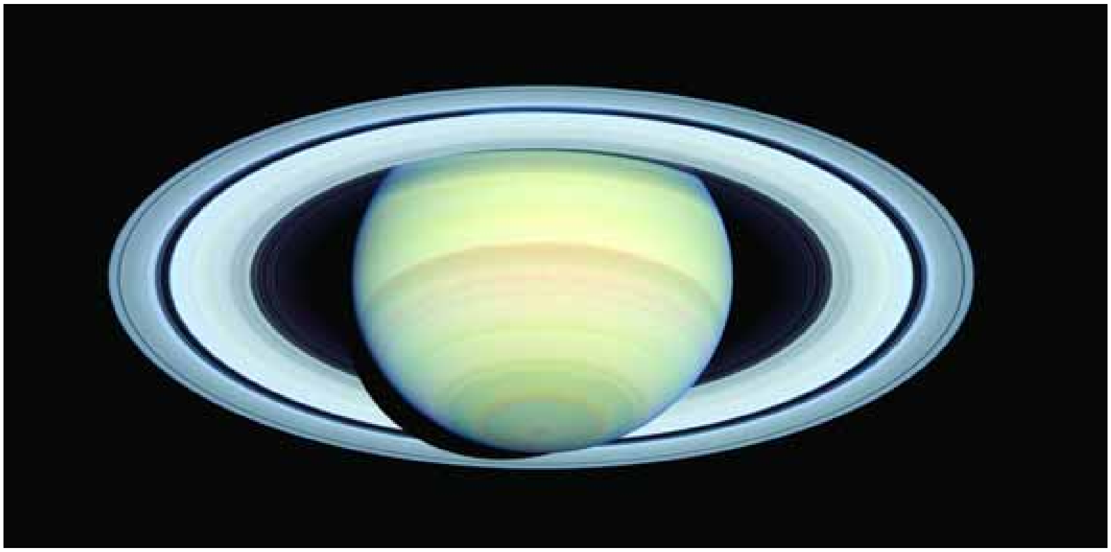
And we could go down to the docks and meet the disembarking hordes, prospectors, fortune seekers, entrepreneurs (like Levi Strauss), and even the rogues and scoundrels of the wild west and the Barbary Coast. Some struck it rich, some failed, some went home. But many stayed to carve out a new world. ...

And so my One Urgent Request...Give Us More! Distill the Spirit and Energy of everything you've heard of what is Possible to its Quintessence! Make an MTV Video – An X-Box Game! Show us a human and a robot doing a "High Five" on Mars! ...

Give us your Results in a form powerful enough to keep a nation of nine-year olds Awake All Night!

Knock Our Socks Off!

– *Roger G. Gilbertson*
"comments from the audience"
Commission's San Francisco Public Hearing
April 16, 2004



Saturn grows closer through the eyes of the Cassini spacecraft hurtling toward a rendezvous with the ringed world on June 30, 2004. Both Cassini and the Earth-orbiting Hubble Space Telescope snapped spectacular pictures of the planet and its magnificent rings. Cassini has a very different view of Saturn than Hubble and for the first time, astronomers can compare views of equal sharpness of Saturn from two very different perspectives. (NASA)

other civic organizations to take advantage of the educational and commercial benefits of space exploration. The marketing and communication involved in keeping people informed about and engaged in space exploration cannot be a part-time effort nor a stop-and-start endeavor. Contemporary story-telling techniques should be used to persuade people to make an investment in the space frontier. Robust marketing, advertising, and recruitment campaigns that attract and hold the attention of the American public should be created and implemented.

The Commission believes that great opportunities exist to engage the public through cutting edge multi-media products. Moving images are to today's students what books were to students in generations past. Movies can bring technical space subjects to life for people who have no interest at all in mathematics or science. From IMAX films to Hollywood blockbusters, millions of space enthusiasts look to the big screen (and subsequent video distribution) for the latest in space "stories." The techniques employed by the film industry, applied to actual space science, can result in dynamic narratives that inspire and educate people.

Similarly, video and simulation games are not only a multi-billion dollar industry, they are proving to be effective as learning devices for people of all ages. Space flight simulators have long been used at the various NASA Centers, but only recently have similar programs been incorporated into smaller, hand-held "amusement" versions and made available for public use. The potential for converting hobbies and amusements to more educational pursuits is enormous. NASA could collaborate with video game producers to create live-action learning modules that give players the chance to experiment with orbital mechanics, the principles of spaceflight, and other space-related subjects. A new model for public engagement, which seeks broad grass roots support through coordinated efforts of government, industry, and non-profit institutions, uses professional communicators to formulate its messages, and incorporates exciting multi-media products to infuse space exploration into our culture as never before. Thus, such an effort is well aligned with the goals of the space exploration vision itself, which seeks to vastly expand our presence in space.

Section VI

Concluding Comments

We must not underestimate the difficulty and risk of achieving the goals and benefits of the space exploration vision. It is difficult to hold the attention of the public in today's data-rich and rapidly changing environment, but we need their commitment. There must also be a commitment between Administrations and Congresses for adequate and sustained long-term funding. We must have these commitments if we are to succeed in achieving our exploration objectives in the decades ahead.

We must accept failure and risk along the way – because we face unknown environments and we are pushing the state of the art in technology – not because of preventable mistakes or incompetence. We must transform the operation of government agencies, requiring difficult changes in culture, organizational structure, and cooperation. The government must be prepared to shed programs that do not contribute to the fulfillment of this vision.

We must accept failure and risk along the way – because we face unknown environments and we are pushing the state of the art in technology – not because of preventable mistakes or incompetence.

We must challenge and rely heavily upon the private sector – major corporations, small business, and entrepreneurs – beyond anything that has ever been attempted in a major government-run program. The government must execute only those activities that are too risky for private sector involvement. The government must change its focus to provide incentives for the commercialization of space, and to create, nurture, and sustain a robust space-based industry.

We must think about our country and its future in competitive terms. The future is for our children, and they must be trained to sustain this nation's quality of life in a more competitive world, through technological achievement and economic growth. We must reverse the decline of students entering into technical fields and the shortage of well-trained science teachers. We must take advantage of the unique opportunity afforded by this vision to inspire our youth and our teachers to focus on mathematics, science, and engineering education.

We must ask and answer bold questions about our origins and our future. We must ponder and innovate and search the depths of space to know our place in the cosmos.

Appendix A

Executive Order

PRESIDENT'S COMMISSION ON
IMPLEMENTATION OF UNITED STATES SPACE EXPLORATION POLICY

By the authority vested in me as President by the Constitution and the laws of the United States of America, and to obtain recommendations concerning implementation of the new vision for space exploration activities of the United States, it is hereby ordered as follows:

Section 1. Establishment. There is hereby established the President's Commission on Implementation of United States Space Exploration (the "Commission").

Sec. 2. Membership. (a) The Commission shall be composed of not more than nine members appointed by the President, taking into account as appropriate the experience of such individuals with respect to governmental, scientific, and technical matters relating to space.

(b) The President shall designate one member of the Commission to serve as Chairman of the Commission.

Sec. 3. Mission. (a) The mission of the Commission shall be to provide recommendations to the President, in accordance with this order, on implementation of the vision outlined in the President's policy statement entitled "A Renewed Spirit of Discovery" and the President's Budget Submission for Fiscal Year 2005 (collectively, "Policy").

(b) The Commission shall examine and make recommendations to the President regarding:

- (i) A science research agenda to be conducted on the Moon and other destinations as well as human and robotic science activities that advance our capacity to achieve the Policy;
- (ii) The exploration of technologies, demonstrations, and strategies, including the use of lunar and other *in situ* natural resources, that could be used for sustainable human and robotic exploration;
- (iii) Criteria that could be used to select future destinations for human exploration;
- (iv) Long-term organization options for managing implementation of space exploration activities;
- (v) The most appropriate and effective roles for potential private sector and international participants in implementing the Policy;
- (vi) Methods for optimizing space exploration activities to encourage the interest of America's youth in studying and pursuing careers in mathematics, science, and engineering; and
- (vii) Management of the implementation of the Policy within available resources.

Sec. 4. Administration. (a) The National Aeronautics and Space Administration (NASA) shall provide, to the extent permitted by law, administrative support and funding for the Commission. The Commission is established in NASA for administrative purposes only.

(b) Members of the Commission shall serve without compensation for their work on the Commission. Members appointed from among private citizens of the United States, however, while engaged in the work of the Commission, may be allowed travel expenses, including per diem in lieu of subsistence, as authorized by law for persons serving intermittently in Government service (5 U.S.C. 5701-5707), to the extent funds are available.

(c) Insofar as the Federal Advisory Committee Act (5 U.S.C. App. 2) (the "Act"), as amended, may apply to the Commission, any functions of the President under that Act, except for those in section 6 of that Act, shall be performed by the Administrator of NASA (the "Administrator"), in accordance with the guidelines that have been issued by the Administrator of General Services.

(d) The Commission shall conduct occasional meetings as appropriate, including at various locations throughout the United States, to solicit views and opinions from the public, academia, and industry.

(e) The Commission shall not have access to information classified pursuant to Executive Order 12958 of April 17, 1995, as amended.

Sec. 5. Report. The Commission shall submit its final report to the President through the Administrator within 120 days of the first meeting of the Commission.

Sec. 6. General Provisions. (a) This order is intended only to improve the internal management of the executive branch and it is not intended to, and does not, create any right or benefit, substantive or procedural, enforceable at law or in equity by a party against the United States, its departments, agencies, instrumentalities or entities, its officers or employees, or any other person.

(b) The Commission shall terminate within 60 days after submitting its final report.

/s/
George W. Bush
The White House
Washington, D.C.
January 27, 2004

Appendix B

Commission Charter

Official Designation: President's Commission on Implementation of United States Space Exploration Policy

Scope and Objectives: The mission of the Commission shall be to provide recommendations to the President on implementation of the vision outlined in the President's policy statement entitled "A Renewed Spirit of Discovery" and the President's Budget Submission for Fiscal Year 2005 (collectively, "Policy"). The Commission shall examine and make recommendations to the President regarding:

(a) A science research agenda to be conducted on the Moon and other destinations as well as human and robotic science activities that advance our capacity to achieve the Policy;
(b) The exploration of technologies, demonstrations, and strategies, including the use of lunar and other *in situ* natural resources, that could be used for sustainable human and robotic exploration;
(c) Criteria that could be used to select future destinations for human exploration;
(d) Long-term organization options for managing implementation of space exploration activities;
(e) The most appropriate and effective roles for potential private sector and international participants in implementing the Policy;
(f) Methods for optimizing space exploration activities to encourage the interests of America's youth in studying and pursuing careers in mathematics, science, and engineering; and
(g) Management of the implementation of the Policy within available resources.

Duration: The Commission will exist for 180 days, unless earlier renewed.

Reporting Relationship: The Commission will submit its final report to the President through the Administrator within 120 days of the first meeting of the Commission.

Support: NASA will provide administrative support and funding for the Commission. The Commission is established in NASA for administrative purposes only.

Duties: The Board will provide advice and recommendations only.

Costs: The operating cost associated with supporting the Board's functions is estimated to be $2 million, including all direct and indirect expenses. It is estimated that 15 full-time equivalent (FTE) will be required to support the Board.

Meetings: The Commission shall conduct occasional meetings as appropriate, including at various locations throughout the United States to solicit views and opinions from the public, academia, and industry.

Date of Termination: The Commission shall terminate within 60 days after submitting its final report.

Charter Filing Date: February 2, 2004

/s/
Sean O'Keefe
NASA Administrator

Appendix C

Renewed Spirit of Discovery

The President's Vision for U.S. Space Exploration

Background

From the Apollo landings on the Moon, to robotic surveys of the Sun and the planets, to the compelling images captured by advanced space telescopes, U.S. achievements in space have revolutionized humanity's view of the universe and have inspired Americans and people around the world. These achievements also have led to the development of technologies that have widespread applications to address problems on Earth. As the world enters the second century of powered flight, it is time to articulate a new vision that will define and guide U.S. space exploration activities for the next several decades.

Today, humanity has the potential to seek answers to the most fundamental questions posed about the existence of life beyond Earth. Telescopes have found planets around other stars. Robotic probes have identified potential resources on the Moon, and evidence of water – a key ingredient for life – has been found on Mars and the moons of Jupiter.

Direct human experience in space has fundamentally altered our perspective of humanity and our place in the universe. Humans have the ability to respond to the unexpected developments inherent in space travel and possess unique skills that enhance discoveries. Just as Mercury, Gemini, and Apollo challenged a generation of Americans, a renewed U.S. space exploration program with a significant human component can inspire us – and our youth – to greater achievements on Earth and in space.

The loss of Space Shuttles *Challenger* and *Columbia* and their crews are a stark reminder of the inherent risks of space flight and the severity of the challenges posed by space exploration. In preparation for future human exploration, we must advance our ability to live and work safely in space and, at the same time, develop the technologies to extend humanity's reach to the Moon, Mars, and beyond. The new technologies required for further space exploration also will improve the Nation's other space activities and may provide applications that could be used to address problems on Earth.

Like the explorers of the past and the pioneers of flight in the last century, we cannot today identify all that we will gain from space exploration; we are confident, nonetheless, that the eventual return will be great. Like their efforts, the success of future U.S. space exploration will unfold over generations.

Goal and Objectives

The fundamental goal of this vision is to advance U.S. scientific, security, and economic interests through a robust space exploration program. In support of this goal, the United States will:

- Implement a sustained and affordable human and robotic program to explore the solar system and beyond;
- Extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations;

- Develop the innovative technologies, knowledge, and infrastructures both to explore and to support decisions about the destinations for human exploration; and
- Promote international and commercial participation in exploration to further U.S. scientific, security, and economic interests.

Bringing the Vision to Reality

The Administrator of the National Aeronautics and Space Administration will be responsible for the plans, programs, and activities required to implement this vision, in coordination with other agencies, as deemed appropriate. The Administrator will plan and implement an integrated, long-term robotic and human exploration program structured with measurable milestones and executed on the basis of available resources, accumulated experience, and technology readiness.

To implement this vision, the Administrator will conduct the following activities and take other actions as required:

A. Exploration Activities in Low-Earth Orbit

Space Shuttle

- Return the Space Shuttle to flight as soon as practical, based on the recommendations of the Columbia Accident Investigation Board;
- Focus use of the Space Shuttle to complete assembly of the International Space Station; and
- Retire the Space Shuttle as soon as assembly of the International Space Station is completed, planned for the end of this decade;

International Space Station

- Complete assembly of the International Space Station, including the U.S. components that support U.S. space exploration goals and those provided by foreign partners, planned for the end of this decade;
- Focus U.S. research and use of the International Space Station on supporting space exploration goals, with emphasis on understanding how the space environment affects astronaut health and capabilities and developing countermeasures; and
- Conduct International Space Station activities in a manner consistent with U.S. obligations contained in the agreements between the United States and other partners in the International Space Station.

B. Space Exploration Beyond Low-Earth Orbit

The Moon

- Undertake lunar exploration activities to enable sustained human and robotic exploration of Mars and more distant destinations in the solar system;
- Starting no later than 2008, initiate a series of robotic missions to the Moon to prepare for and support future human exploration activities;
- Conduct the first extended human expedition to the lunar surface as early as 2015, but no later than the year 2020; and
- Use lunar exploration activities to further science, and to develop and test new approaches, technologies, and systems, including use of lunar and other space resources, to support sustained human space exploration to Mars and other destinations.

Mars and Other Destinations

- ✧ Conduct robotic exploration of Mars to search for evidence of life, to understand the history of the solar system, and to prepare for future human exploration;
- ✧ Conduct robotic exploration across the solar system for scientific purposes and to support human exploration. In particular, explore Jupiter's moons, asteroids and other bodies to search for evidence of life, to understand the history of the solar system, and to search for resources;
- ✧ Conduct advanced telescope searches for Earth-like planets and habitable environments around other stars;
- ✧ Develop and demonstrate power generation, propulsion, life support, and other key capabilities required to support more distant, more capable, and/or longer duration human and robotic exploration of Mars and other destinations; and
- ✧ Conduct human expeditions to Mars after acquiring adequate knowledge about the planet using robotic missions and after successfully demonstrating sustained human exploration missions to the Moon.

C. Space Transportation Capabilities Supporting Exploration

- ✧ Develop a new crew exploration vehicle to provide crew transportation for missions beyond low-Earth orbit;
  - Conduct the initial test flight before the end of this decade in order to provide an operational capability to support human exploration missions no later than 2014;
- ✧ Separate to the maximum practical extent crew from cargo transportation to the International Space Station and for launching exploration missions beyond low-Earth orbit;
  - Acquire cargo transportation as soon as practical and affordable to support missions to and from the International Space Station; and
  - Acquire crew transportation to and from the International Space Station, as required, after the Space Shuttle is retired from service.

D. International and Commercial Participation

- ✧ Pursue opportunities for international participation to support U.S. space exploration goals; and
- ✧ Pursue commercial opportunities for providing transportation and other services supporting the International Space Station and exploration missions beyond low-Earth orbit.

President George W. Bush
January 14, 2004

Appendix D

Member Biographies

Edward C. "Pete" Aldridge, Jr.

Pete Aldridge is a 42-year veteran of aerospace technology leadership, serving the Nation for more than 18 years in the Department of Defense, most recently as the Under Secretary for Acquisition, Technology, and Logistics. His DoD career began as an operations research analyst. Later he became Under Secretary and then Secretary of the Air Force under President Reagan. Aldridge was previously chief executive officer of The Aerospace Corporation and president of McDonnell Douglas Electronic Systems Company. He earned his B.S. in aeronautical engineering from Texas A&M University and an M.S. in aeronautical engineering from Georgia Tech.

Carleton S. Fiorina

Carleton Fiorina serves as chairman and chief executive officer of Hewlett-Packard, which she joined in July 1999. Her career is extensive in technology, having served in senior executive leadership positions at AT&T and Lucent Technologies. She holds B.A.'s in philosophy and history from Stanford; a B.A. in business administration from the Robert H. Smith School of Business at the University of Maryland as well as an M.S. from MIT's Sloan School.

Michael P. Jackson

Michael Jackson is senior vice president for AECOM Technology Corporation. He is the former U.S. Department of Transportation Deputy Secretary. Before coming to DOT, Jackson was chief operating officer of Lockheed Martin IMS's intelligent-transportation systems unit. He had served in two earlier Administrations, in positions at the White House, the Department of Transportation and the Department of Education. Jackson earned his B.A at the University of Houston and a Ph.D. in government from Georgetown University.

Laurie A. Leshin

Laurie Leshin is the director of Arizona State University's Center for Meteorite Studies and the Dee and John Whiteman Dean's Distinguished Professor of geological sciences at the university. Her research focuses on understanding the formation and evolution of our solar system and its planets. She performs detailed analyses of extraterrestrial rocks in the laboratory, and is an active participant in several NASA flight projects to Mars and comets. Her Ph.D. is from the California Institute of Technology.

Lester L. Lyles

General Lyles retired from the U.S. Air Force after more than 35 years, rising from the Air Force ROTC Program to become a 4-star general, commander of the Air Force Materiel Command. The command conducts research, development, test and evaluation, and provides acquisition management and logistics support necessary to keep Air Force weapon system at-the-ready. Lyles holds a B.S. from Howard University, Washington, D.C. and an M.S. in mathematics and nuclear engineering from New Mexico State University.

Paul D. Spudis

Paul Spudis is a planetary scientist at the Johns Hopkins University Applied Physics Laboratory. He studies impact and volcanic processes on the planets, specializing in the geology of the Moon. He was the deputy leader of the science team for the Department of Defense Clementine mission to the Moon in 1994. Spudis has served on several NASA and National Academy of Sciences advisory committees and was a member of the White House Synthesis Group, which examined architectures for lunar and Martian exploration in 1991. His B.S. in geology is from Arizona State University; his M.S. is from Brown University, and his Ph.D. is from Arizona State University.

Neil deGrasse Tyson

Neil deGrasse Tyson is an astrophysicist and the Frederick P. Rose Director of the Hayden Planetarium in New York City. Author of seven popular-level books on the universe, Tyson's professional research interests include star formation, exploding stars, dwarf galaxies, and the structure of the Milky Way. He recently served on the President's Commission on the Future of the U.S. Aerospace Industry. Tyson earned his B.A. from Harvard and his Ph.D. in astrophysics from Columbia University.

Robert S. Walker

Robert Walker is chairman of The Wexler & Walker Public Policy Associates, a firm specializing in telecommunications and technology issues. Walker served in the U.S. Congress from 1977 to 1997, representing his home state of Pennsylvania. While in Congress he was the chairman of the House Science Committee, with NASA oversight. Walker served as the chair of the Commission on the Future of the U.S. Aerospace Industry in 2001. He obtained a B.S. from Millersville University and an M.A. from the University of Delaware.

Maria T. Zuber

Maria Zuber is the E. A. Griswold Professor of Geophysics at the Massachusetts Institute of Technology where she also leads the Department of Earth, Atmospheric, and Planetary Sciences. Zuber has been involved in more than half a dozen NASA planetary missions aimed at mapping the Moon, Mars, Mercury, and several asteroids. She received her B.A. in astrophysics from the University of Pennsylvania and Sc.M. and Ph.D. in geophysics from Brown University. She was on the faculty Johns Hopkins University and served as a research scientist at Goddard Space Flight Center in Maryland.

Appendix E

Commission Staff

Designated Federal Official

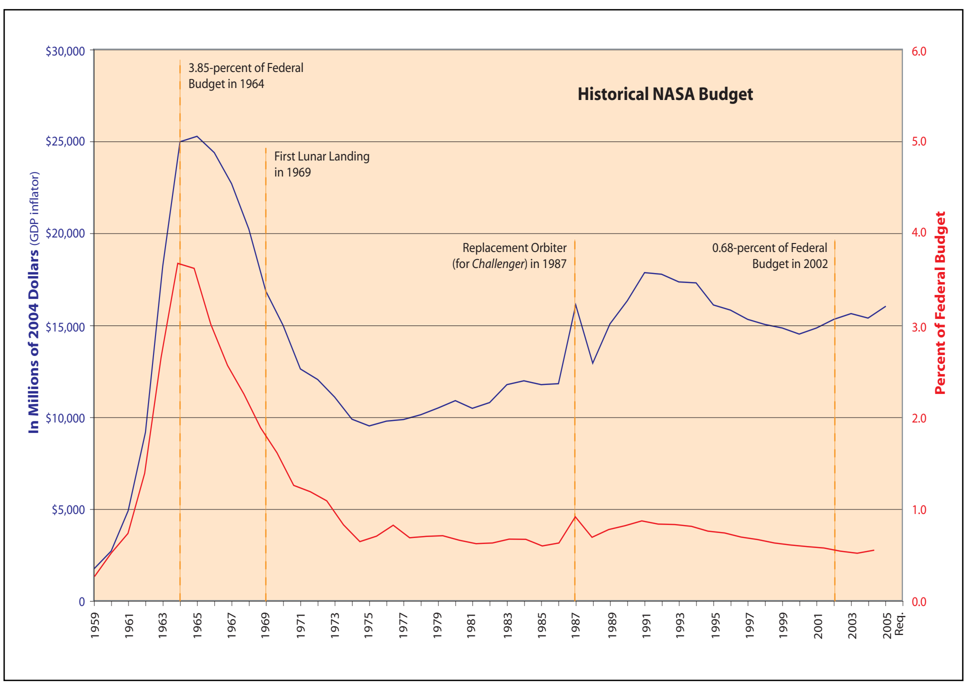
Steven G. Schmidt, Executive Director
Special Assistant to the Administrator
NASA Headquarters

ANSER Support

Jay Baumgartner
Steve Bull
David Semon
John Starcher

Staff

Tammy Belk
Marguerite Broadwell
Jeanette Covington
Andrew Falcon
Susan Flowers
Paula Frankel
Charles Horner
Dennis R. Jenkins
Jeffrey Jezierski
Yvonne Kellogg
Sharon Martin
Steven Miley
Michele O'Connell
Carolyn Saldana
Andrew Schain
Jana T. Schultz
Susan Switzer



Historically, the NASA budget has seldom exceeded one percent of the federal budget except for a short time during the Apollo program. During the last two decades, the NASA budget has represented about 0.85 percent of the federal budget, and is presently at its low ebb. (Source: NASA)

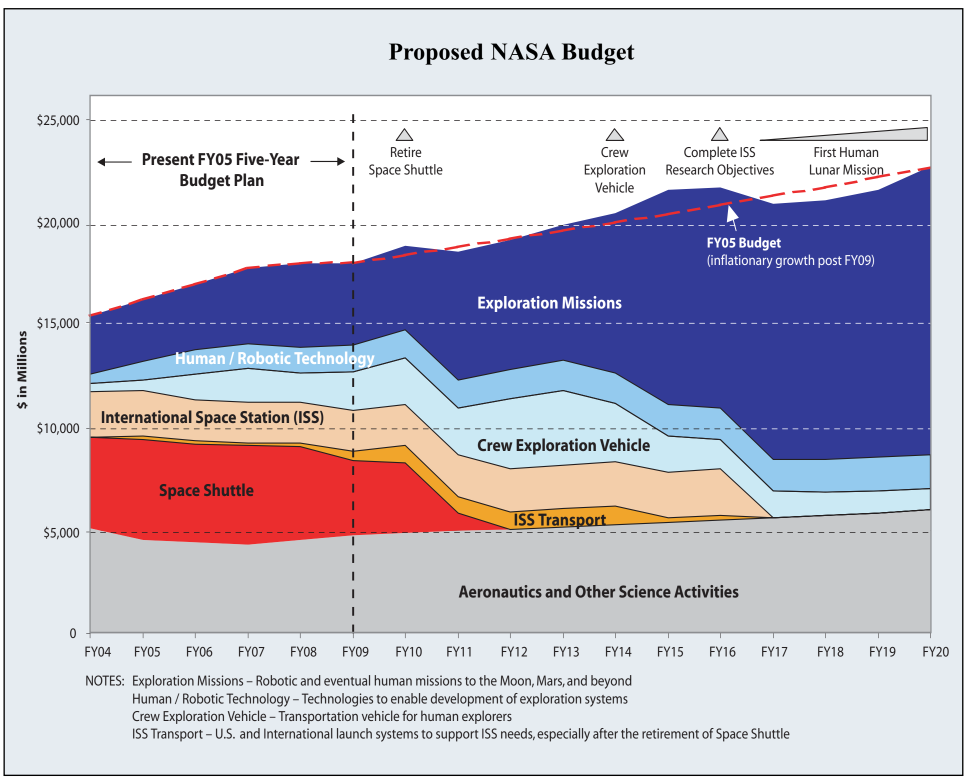
Appendix F

NASA Budget

A fundamental premise of the new vision is that current rates of NASA spending will permit significant advances in our space faring capability, provided that we are able to focus our efforts in a long-term strategic direction.

Much has been written in the press about the costs of the new vision and nearly all of it is wrong. The President proposes to initially augment the NASA budget by less than one billion dollars per year, the increase being spread over the next four years. After that, he proposes to let the NASA budget grow to keep pace with the rate of inflation.

Two charts reproduced on pages 56 and 57 show the historical NASA budget (plotted in constant current year dollars) and the projected budget for the early stage of the new exploration vision. These two charts collectively show that NASA funding growth has been within 20% of the level of inflation for the last 20 years, yet is proposed to grow at the level of inflation for the next 15 years. Thus, the new vision does not require large amounts of new funding, but only that future spending be channeled into our new strategic direction, and that milestones be flexible in light of available funding levels.



Prior to the announcement of the new vision, NASA's five-year budget plan totaled $86 billion. Given the approximately $15.4 billion the agency received in 2004, that plan already had factored an average annual growth rate of 3.5 percent: enough for inflation plus a little bit extra. The new plan changes that to a five-percent growth rate for the first three years and one percent for the following two years, providing an additional $1 billion over five years. That extra funding, however, comes at a price: under the current plan the two out years – 2008 and 2009 – will get increases that will likely be below the inflation rate (which was 1.9% in 2003). (Source: NASA)

Appendix G

Hearings and Trips

Public Hearings[1]

February 11, 2004
National Transportation Safety Board
Washington, D.C.

March 3-4, 2004
United States Air Force Museum
Wright-Patterson Air Force Base, Ohio

March 24-25, 2004
Georgia Tech
Atlanta, Georgia

April 15-17, 2004
Galileo Academy of Science and Technology
San Francisco, California

May 3-4, 2004
Asia Society
New York City

Fact Finding Trips

March 8, 2004
Jet Propulsion Laboratory
Pasadena, California

March 15, 2004
Lyndon B. Johnson Space Center
Houston, Texas

April 6, 2004
John F. Kennedy Space Center
Kennedy Space Center, Florida

April 7, 2004
George C. Marshall Space Flight Center
Huntsville, Alabama

April 26, 2004
Robert H. Goddard Space Flight Center
Greenbelt, Maryland

1. In addition to its public hearings, the Commission solicited views from the public via its web page. The Commission's web page registered over 6 million hits and received some 6,000 written submissions

Appendix H

Witnesses

Buzz Aldrin
Ariel Anbar
Roger Angel
Patricia Arnold
Ghassem Asrar
Norman Augustine

Blaine Baggett
Michael Balzano
Shannon Bartell
James Benson
Frank Benz
John Bernardoni
M. Philippe Berterottiere
Pam Biegert
Mark Bitterman
Ken Bowersox
Joseph Boyle
Charles Bofferding
Ray Bradbury
Lee Briscoe
Charles Browning
Bruce Buckingham
Garry Burdick
Glenn Burran

Robert Cabana
Marco Caceres
Michael Carr
Andy Cheng
Richard Cook
Steve Cook
John Copeland
Craig Covault
Mike Cross
Daniel Curran

Jeff Davis
Eric DeJong
John Delano
Bob Devlin
Peter Diamandis
Tom Duncavage
Michael Duke
Cort Durocher

Chad Edwards
Nick Eftimiades
Charles Elachi
Raymond Ernst
Dominic Farrar
Orlando Figueroa
Margaret Finarelli
Lennard Fisk
Stephen Fleming
Steve Francois
Mary Ann Frey
Louis Friedman

Marc Garneau
Jim Garvin
Tom Gavin
Harold Gehman
Rich Gelfond
Richard Geraci
Reecie Giesecke
Newt Gingrich
John Glenn
David Goodreau
Jeff Greason
Joel Greenberg
M.R.C. Greenwood
John Grunsfeld
Walt Guy

John Hager
Jeff Harris
James Hattaway, Jr.
Frederick Hauck
James Heald
Milt Heflin
Daniel Hegeman
Shar Hendrick
John Higginbotham
Kiyoshi Higuchi
Lawrence Holland
Jefferson Howell
Tim Huddleston

Bill Jeffery
Frank Jordan

Michael Kearney
Robert Kehler
James Kennedy
Scott Kerr
Mary Kicza
Bill Kilpatrick
Dave King
Narayanan Komerath
Roger Krone
Susan Kroskey
Tony Lavoie
Daniel Leaf
Michael Leahy, Jr.
Victor Lebacqz
Gentry Lee
Ron Lee
David Leestma
Dave Lehman
David Levy
Steve Lewis
Volker Liebig
Adena Loston
Freeda Lowry
Edward Lu
Ray Lugo
Jonathan Lunine
Glen Lutz

Gregory Martin
Michael Martin
William McCasland
Dan McCleese
Jim McMurtray
Harry McSween, Jr.
Pam Melroy
Stanley Mohler
Barbara Morgan
Dave Morrison
James Mosquera
Michael Mott
Elon Musk

Conrad Nagle
Paul Nielsen

Bob Oberto
Paul Ohme
Sean O'Keefe
Richard Omlor
Jay Onken

Allen Patterson
Gary Payton
Neal Pellis
Trish Pengra
Donald Pettit
Catherine Pilachowski
Dave Poston

Jeff Rainey
Bill Readdy
Gary Robbins
June Scobee Rodgers
Fred Roe
Stan Rosen
Axel Roth
Richard Russell
Vincent Russo

Daniel Sacotte
Frank Samuels
Mike Sander
Rusty Schweikart
Winston Scott
Jon Sharpe
Ed Simms
Pat Simpkins
Chris Singer
Frank Six
Maynette Smith
Scott Smith
William Smith, Jr.
David Spergel
Steve Squyres
Tom Stafford
Craig Staresinich
Craig Steidle
Doug Stetson
Daniel Stone

John "Tip" Talone, Jr.
Tony Tether
Ronald Turner
Sandra Turner

Jakob van Zyl
John Vickers

Myles Walton
Tereasa Washington
Ed Weiler
Jerry Wheeler
George Whitesides
Woodrow Whitlow
William "Red" Whittaker
Brett Williams
Byron Wood

Dean Zvorak

Appendix I

Legal Compliance

Based on the objectives and purposes of the Commission, the NASA General Counsel has determined that the activities of the Commission fall within the scope of the Federal Advisory Committee Act (5 U.S.C. App. 1 et seq.). It is neither intended nor anticipated that any of the Commission 's activities will concern "particular matters" within the meaning of Section 208 of Title 18, U.S. Code.

Some members of the Commission, through their private employment, have interests in the aerospace community and, consequently, the activities of NASA. Although the scope of the Commission, as set forth in the Charter, renders the likelihood of an actual conflict of interest remote, this factor was nonetheless taken into serious consideration when they were appointed to the Commission. It was the determination of the appointing authority that the private interests of the Commissioners were not so paramount as to impede their objectivity or integrity as members of the Commission. These determinations were made by the appointing authority only after careful review of the duties of the Commission and the expected scope of the Commission's activities, the individual financial interests of each Commissioner, and identification of any steps necessary to ensure full compliance with conflict of interest rules and the avoidance of even the appearance of impropriety. Further, a NASA attorney reviewed all Commission activities in advance.

Although the nature of the Commission's work rendered any potential conflicts remote, the Commissioners sought to avoid even the appearance of a conflict of interest. The Commissioners thus elected not to participate in receiving or commenting on any testimony provided by companies or organizations with which they have business or financial relationships, nor to participate in decisions, deliberations, or recommendations that might affect companies or organizations with which they have business or financial relationships.

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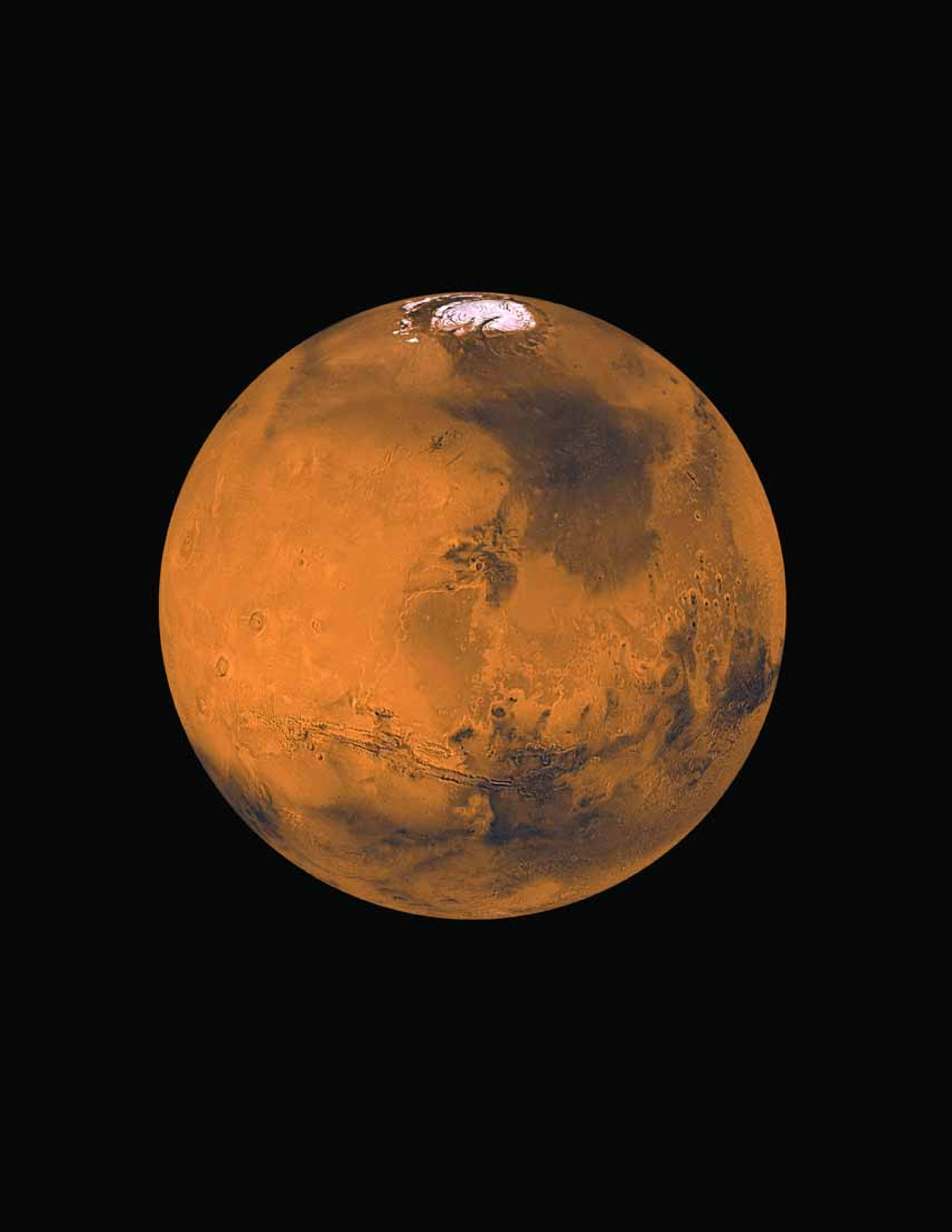

Moon, Mars and Beyond …

Report of the

President's Commission on Implementation of United States Space Exploration Policy

June 2004