Executive Summary

Apollo 11 first placed America on the Moon on July 20, 1969. This extraordinary accomplishment confirmed the United States' technological ascendancy for a generation. On the 20th anniversary of Apollo 11, President George Bush announced a new vision for America in the 21st century — a vision that will return us to the Moon to stay, and onward to Mars by 2019. This vision, the Space Exploration Initiative, represents one of the greatest technological challenges the world has ever known.

> "The challenges of the Space Exploration Initiative are great, but so is the quality of American talent and ingenuity, and so is the leadership of the American people. And . . . it is America's destiny to lead."
>
> *President George Bush*

Vision for America

The Space Exploration Initiative provides a focus that allows the United States to gain control of our destiny in space. In doing this, six "visions" guide and direct our space efforts. These are:

Knowledge of our Universe. We strive to understand the origin and history of our Solar System, the origin of life, and the ultimate fate of our universe. People are the best explorers, but they often need machines to help. *The Space Exploration Initiative is an integrated program of missions by humans and robots to explore, to understand and to gain knowledge of the universe and our place in it.*

Advancement in Science and Engineering. Returning to the Moon and onward to Mars requires the best engineering and scientific talent our nation can muster. Through a long range commitment to space, we stimulate our national education system and inspire students to learn. Motivated students are essential to excellence in education. *The Space Exploration Initiative will motivate and inspire the new generations on which our future as a nation depends.*

United States Leadership. The Space Exploration Initiative provides us with an opportunity to re-establish and maintain American preeminence in technological innovation and space leadership. Other nations have gained the initiative in certain areas and have become leaders in a tradition of space exploration that America pioneered. *Leadership cannot be declared . . . it must be earned.*

Technologies for Earth. America's recent history has demonstrated that our space program stimulates a wide range of technological innovations that find abundant application in the consumer marketplace. Space technology has revolutionized and improved our daily lives in countless ways, and it will continue to do so. Energy from space, advances in solar power and fusion fuels, useful materials for advanced communications, new resources, medical breakthroughs, and greater insight into the human potential are some of the direct benefits we can expect. *The Space Exploration Initiative provides focused goals to effect practical and beneficial technological change.*

Commercialization of Space. Initiatives by the private sector are goals of our National Space Policy. Space is a limitless, untapped source of materials and energy, awaiting industrial development for the benefit of humanity. *Commercial products, such as zero gravity derived materials, and service industries, like advanced global communications, all become increasingly feasible and profitable once routine, reliable and affordable access to space is available.*

Strengthened U.S. Economy. New technologies open new markets. An investment in the high technology needed for space exploration maintains and improves America's share of the global market and enhances our competitiveness and balance of trade. It also directly stimulates the scientific and technical employment bases in our country, sectors whose health is vital to our nation's economic security. *The Space Exploration Initiative is an investment in the future of America.*

Why the Moon?

Earth's closest neighbor in space, the Moon, is surprisingly complex. It is an object for detailed exploration, a platform from which to observe and study the universe, a place to live and work in the environment of space, and a natural source of materials and energy for an emerging space-based economy.

The Moon offers a record of four billion years of planetary history. Its violent birth and history of bombardment from space is closely related to events on the early Earth. The Moon provides a natural laboratory for detailed study of geology and planetary formation, the output of our Sun over its lifetime, and the elements of our universe. The Moon's 14 Earth-day night, crystal clear, airless sky and stable ground provide a superb platform for astronomy.

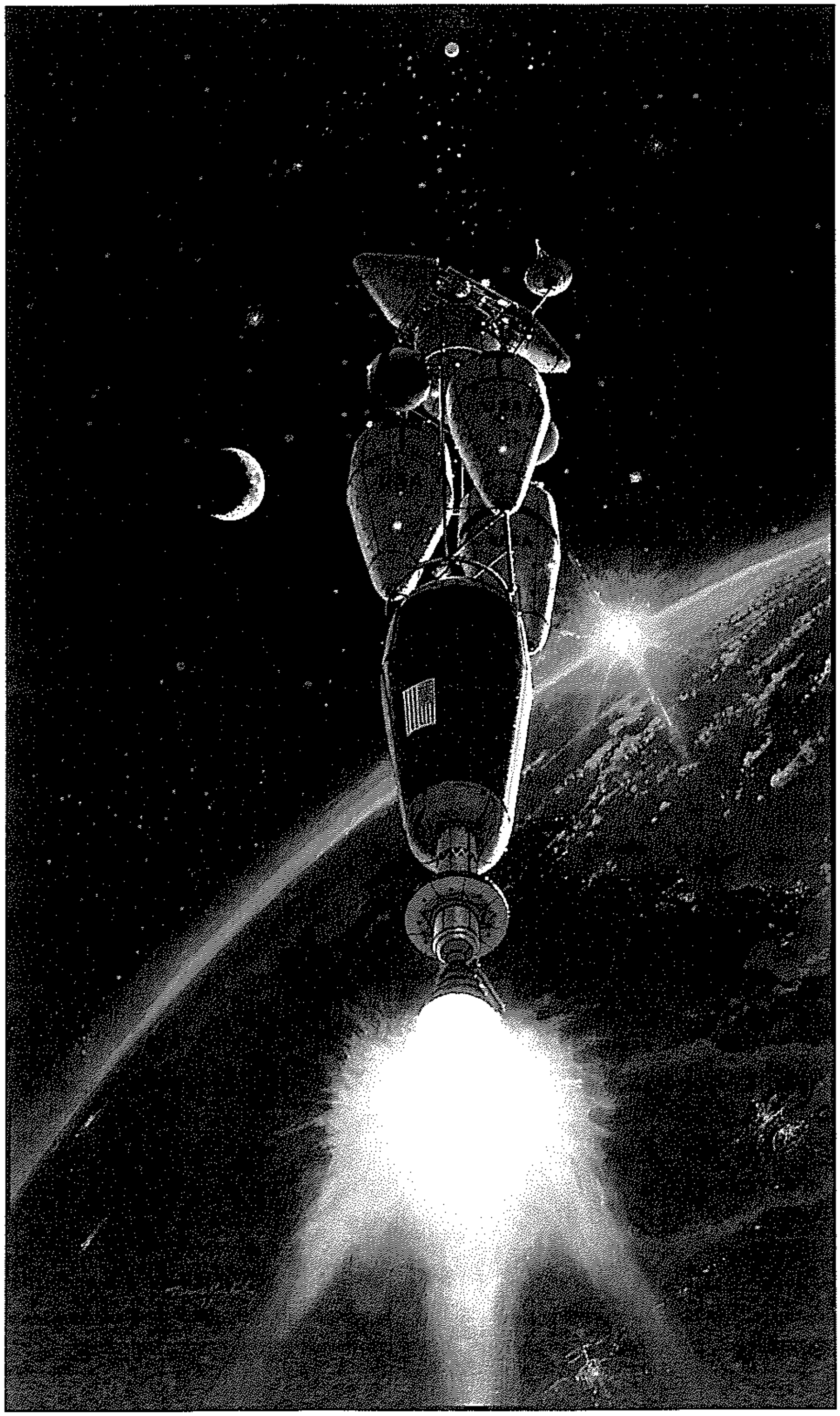
The Moon is the nearest object in space where people can live under conditions similar to those we will face on other planets. Thus, the Moon is a natural test bed to prepare for missions to Mars through simulation, systems testing, operations and studying human capabilities.

The Moon is a rich source of materials and energy for use in space. Abundant metals, ceramics and recoverable amounts of hydrogen, carbon and oxygen can provide propellants and human life support from the lunar surface. The 14 Earth-days of a lunar daytime provide abundant solar energy. Our Moon provides a rich scientific and economic waystation for human expansion into the Solar System.

Why Mars?

Of all the planets in our Solar System, Mars is the most like Earth. With a thin atmosphere, weather, seasons

Leaving Earth Orbit



and a 25-hour day, Mars has a diverse and complex surface, including ice and evidence of water. Although conditions on Mars cannot support life now, a variety of evidence suggests that Mars was warmer, wetter and had a much denser atmosphere early in its history. Life may have existed. If so, fossil evidence may be found.

Mars has undergone a complicated geologic evolution. Its surface consists of gigantic canyons, huge volcanoes, gorges carved by running water, vast regions of sand dunes and a polar ice cap. Understanding the periodic changes in climate that have occurred on Mars will help us understand the Earth's climate and predict its future behavior, a topic vital to the survival of life on Earth.

Architectural Considerations

At its closest point, Mars is 35 million miles from Earth. This distance increases to 230 million miles when we are on opposite sides of the Sun. By comparison, the Moon is only a quarter-million miles away — a three-day journey. The challenges of a Mars expedition stem from the distances, the long times away from Earth, the environment of deep space and Mars' unique characteristics.

A total Mars mission duration depends on both the round trip travel time and the time spent on the planet's surface. Conventional chemical propulsion missions will take about 230 days one way, and require long surface stays of about 500 days to allow the planets to realign before returning home. Advanced nuclear propulsion technologies can shorten the transit time, provide flexible surface stay times, significantly reduce the propellant mass to low Earth orbit and increase the available launch opportunities.

Shorter travel times are desirable to reduce the impact of the deep space environment on the crew and mission equipment. During the space voyage, expected hazards include radiation from galactic cosmic radiation and solar flares, the lack of normal gravity, psychological stress from long term isolation, and equipment degradation.

The challenges of a Mars trip will require several hundred tons of equipment and fuel for the expedition. Thus, we will require a heavy lift launch capability to minimize assembly in Earth orbit. Nuclear propulsion technology allows reduced weight, approximately one-half that of chemical systems, and achieves faster interplanetary trip times. At Mars, we need Earth-independent operations, since round trip communications times will vary from seven to 40 minutes. We also need improved long term life support systems that operate for lengthy time periods without resupply.

The planetary surface of Mars provides challenges different from those of the Moon. The planet is large — about one-third the size of Earth. It has a diverse topography, with 80,000 foot volcanos, three times as high as Mount Everest and as large as the state of Montana, and canyons as long as our continent is wide. Mars' atmosphere is mostly carbon dioxide, and it is known to have periodic dust storms. These features will require unique power systems, landers, rover vehicles and human habitats.

Architectures

The foundation of the architectures reflects three areas of emphasis: human presence, exploration and science, and space resource development for the benefit of Earth. Different architectures vary with the degree of human presence, the level to which exploration and science are pursued, the extent to which space resources are developed, as well as the relative emphasis between lunar and Martian activity.

Four architectures have been identified and they provide significant differences across the possible areas of interest. They are:

Mars Exploration: The emphasis of this architecture is on Mars exploration and science. The first human mission to the Moon occurs in 2005. The lunar infrastructure is developed only to the degree necessary to test and gain experience with Mars systems and operations and to simulate Mars stay times. The Moon is explored while developing operational concepts for Mars.

Robotic precursor missions are used to scout the territory before committing to a landing site for Mars. The first human mission to Mars occurs in 2014, with a surface stay of 30 to 100 days. The next mission is planned for 2016 for a 600 day stay. This architecture is designed to be a minimal approach to achieving the Initiative objectives.

Science Emphasis for the Moon and Mars: The Moon and Mars are emphasized equally, and an early global assessment of both bodies permits a variety of initial missions designed to better understand global diversity. The first human mission to the Moon is 2003. Life sciences data required for Martian missions are generated through extensive operations on the Moon. Human-controlled robotics assist the planning and execution of human activity on the surface. Instrument emplacement focuses on early deployment of portable instruments which gather observation data independent of lunar location. In the latter stages of architecture implementation, emphasis shifts to larger scientific experiments and instruments after developing surface capabilities for-construction, maintenance and operations. Continuous exploration activities yield a significant scientific return though the use of a balanced mix of human and robotic exploration techniques.

Subsequent to the establishment of the desired long term operational capabilities for exploration and science on the Moon, human missions to Mars take place beginning in 2014. All knowledge gained by the activities in lunar orbit, and on the surface becomes part of and is complementary to the dress rehearsal for the Mars mission.

The Moon to Stay and Mars Exploration: This architecture emphasizes permanent human presence on the Moon, combined with the exploration of Mars. One of the major objectives is to build towards life support self-sufficiency for breathing gases and food production on the Moon.

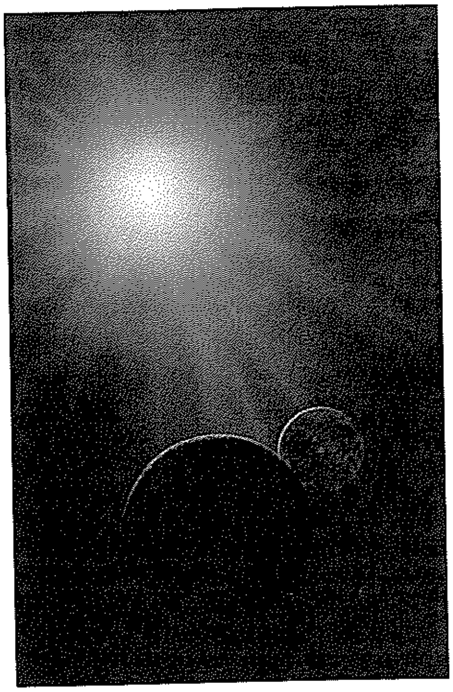
The permanent presence of humans on the Moon, beginning in 2004, gives us an impressive scientific capability. Science on the Moon will emphasize exploration and observation. For lunar exploration, extended traverses in pressurized rovers will permit detailed study of complex and puzzling lunar features and processes. Robotic assistants will extend human reach for great distances across the lunar surface. With a permanent human presence on the Moon, advanced and sophisticated astronomical observatories can be installed and maintained.

Extensive space and lunar surface operations are conducted on the Moon to provide the necessary life sciences and engineering data to prepare for future exploration missions to Mars. The first human mission to Mars is in 2014, with a surface stay of 30 to 100 days.

Space Resource Utilization: This architecture makes maximum use of available space resources to support the exploration missions directly. It also seeks to develop a large class of available resources for a broader range of transportation, habitation, life sciences, energy production, construction and many other long term

Architectures

- **I. Mars Exploration**
- **II. Science Emphasis for the Moon and Mars**
- **III. The Moon to Stay and Mars Exploration**
- **IV. Space Resource Utilization**



Beyond the Moon

activities. In preparation for the first human return mission, a robotic experimental resource producing plant is landed on the Moon in 2003. The first human mission to the Moon takes place in 2004 and to Mars in 2016. On Mars, the basic exploration would be done on the first two missions with the addition of more resource development, which could be expanded on missions beyond the first two. In the long term, this architecture may benefit Earth by providing Helium-3 to fuel Earth-based fusion reactors and beaming solar-produced electricity to Earth.

Transportation

After study of the various transportation options, it was concluded that chemical propulsion from low Earth orbit, as used in the Apollo program, is still the preferred way to get to the Moon. However, significantly heavier lift capability will be required to support any of the architectures. For the Mars transit from Earth orbit, the nuclear thermal rocket is the preferred propulsive system to allow significantly reduced mass to low Earth orbit, shorter transit times and greater operational flexibility.

Supporting Technologies

Technology will provide the tools necessary for safe and cost effective exploration of the Moon and Mars. Technology development is required in the following areas:

1) Heavy lift launch with a minimum capability of 150 metric tons with designed growth to 250 metric tons
2) Nuclear thermal propulsion
3) Nuclear electric surface power to megawatt levels
4) Extravehicular activity suit
5) Cryogenic transfer and long term storage
6) Automated rendezvous and docking of large masses
7) Zero gravity countermeasures
8) Radiation effects and shielding
9) Telerobotics
10) Closed loop life support systems
11) Human factors for long duration space missions
12) Lightweight structural materials and fabrication
13) Nuclear electric propulsion for follow-on cargo missions
14) In situ resource evaluation and processing

At first glance, the implementation of the architectural approaches outlined appears daunting. It is indeed complex. But it is noteworthy that America's ability to return to the Moon and to begin the exploration of Mars depends on two fundamental technologies:

1) Restoration of a heavy lift launch capability
2) Redevelopment of a nuclear propulsion capability

This nation had both of these capabilities in the early 1970s. In addition to these two areas, the 12 other technologies identified, if successfully developed, offer the potential for vastly enhancing the exploration of the Moon and Mars.

Organization and Acquisition Management

The Space Exploration Initiative represents a major management challenge as well as a significant technological challenge to this country. The capability exists in this nation to accomplish the Space Exploration Initiative within the combined resources of the government, industry and the academic community. It requires management that allows for crisp and timely decision making, plus the assured resources to reach its goals.

An Executive Order should be issued to cite the basic charter of the National Program Office for the Space Exploration Initiative Organization. It should define the leadership role of NASA and the cooperative relationships among various governmental departments and agencies. The Executive Order should clearly enumerate the staffing, budgeting and reporting relationships and responsibilities of the affected agencies.

The Synthesis Group reviewed numerous successful and unsuccessful major aerospace, industry and government programs, and studied various acquisition improvements and key factors that helped reduce the cost of the most successful aerospace programs.

In managing the Space Exploration Initiative, NASA should be authorized to tailor the existing procurement system and devise new procedures to fit the needs of this major new program.

The opportunity for a number of international cooperative ventures exists.

Commercial potential abounds within the framework of the Initiative. Launch services, communications satellites, robotics, production of materials in space for use in space and on the Earth, and electronics technology represent a few of these potential areas.

Recommendations

Specific recommendations are provided for the effective implementation of the Space Exploration Initiative.

RECOMMENDATION 1

Establish within NASA a long range strategic plan for the nation's civil space program, with the Space Exploration Initiative as its centerpiece.

> ". . . the jewel represented by the vision of a seemingly unattainable goal, the technologies engendered, and the motivation provided to our nation's scientists and engineers, its laboratories and industries, its students and its citizens. Hence that the Mission from Planet Earth be established with the long term goal of human exploration of Mars, underpinned by an effort to produce significant advances in space transportation and space life sciences."[1]

A strategic plan will provide decision points to allow flexibility during the life of the program, concentrate management activities of diverse departments, provide budget guidelines and identify technology pathways. The plan must be based on a detailed governmental (NASA, the Department of Defense, the Department of Energy) analysis of the Synthesis Group's four architectures. This analysis should result in further refinement to gain sufficient detail to support relative costing of the architectures. Existing and planned programs should be reviewed for their contributions to this plan. Industry effort should be limited to studying elements of the architectures. As the strategic plan's centerpiece, the Space Exploration Initiative complements the goals of Mission to Planet Earth.[2]

> "We propose . . . to accelerate the development of the NOVA nuclear rocket. This gives promise of some day providing a means for even more exciting and ambitious exploration of space, perhaps beyond the Moon, perhaps to the very end of the solar system itself."
>
> *John Fitzgerald Kennedy*

RECOMMENDATION 2

Establish a National Program Office by Executive Order.

This organization would include Department of Defense and Department of Energy personnel working directly for the National Program Office. With the multi-agency nature of the National Program Office, an Executive Order should be issued to cite the basic charter of the organization, the leadership role of NASA, and the cooperative relationship among various governmental departments and agencies. The Executive Order should clearly enumerate staffing, budgeting and reporting relationships and responsibilities of the affected agencies.

RECOMMENDATION 3

Appoint NASA's Associate Administrator for Exploration as the Program Director for the National Program Office.

This is required to ensure clean lines of management authority over a large, complex program while simultaneously providing a focus for NASA's supporting program elements.[2]

RECOMMENDATION 4

Establish a new, aggressive acquisition strategy for the Space Exploration Initiative.

The Space Exploration Initiative should standardize acquisition rules for the agencies executing the Initiative's various projects. The most streamlined processes available should be adopted for that standard. The Space Exploration Initiative is so great in scope that it cannot be executed in a "business as usual" manner and have any chance for success. The Space Exploration Initiative National Program Director should be designated as the Head of the Contracting Activity. This will allow the director to establish the optimum acquisition procedures within the Federal Acquisition Regulations. Multi-year funding should be provided.

RECOMMENDATION 5

Incorporate Space Exploration Initiative requirements into the joint NASA-Department of Defense Heavy Lift Program.

The Space Exploration Initiative launch requirement is a minimum of 150 metric tons of lift, with designed growth to 250 metric tons. Using Apollo Saturn V F-1s for booster engines, coupled with liquid oxygen-hydrogen upper stage engines (upgraded Saturn J-2s or space transportation main engines), could result in establishing a heavy lift launch capability by 1998.[2]

RECOMMENDATION 6

Initiate a nuclear thermal rocket technology development program.

The Synthesis Group has determined the only prudent propulsion system for Mars transit is the nuclear thermal rocket. Sufficient testing and care must be taken to meet safety and environmental requirements.

RECOMMENDATION 7

Initiate a space nuclear power technology development program based on the Space Exploration Initiative requirements.

The program must concentrate on safe, reliable systems to a megawatt or greater level. These nuclear power systems will be required for use on the Moon before use on the Mars mission.

RECOMMENDATION 8

Conduct focused life sciences experiments.

Implement a definitive life sciences program, along with the necessary experiments and equipment, on Space Station Freedom, consistent with the recommendation of the Advisory Committee on the Future of the U.S. Space Program. These experiments are needed to reduce the uncertainties of long duration space missions.[2]

RECOMMENDATION 9

Establish education as a principal theme of the Space Exploration Initiative.

The Initiative will require scientists, engineers and technicians for its execution. It is a source of interest and expectation to those considering science and engineering careers. The Space Exploration Initiative can contribute directly to undergraduate and graduate education in engineering and science by re-invigorating a university research program in support of the Exploration Initiative as was done during the Apollo program of the 1960s and early 1970s.

RECOMMENDATION 10

Continue and expand the Outreach Program.

The Outreach Program has served a very useful purpose in the Synthesis Group's deliberations. The ideas from the Outreach Program will be turned over to NASA with the recommendation that they review them periodically. The Outreach Program generated not only ideas but also greater interest in the Space Exploration Initiative. Both features should be emphasized. The database should be refreshed with further outreach solicitations, perhaps every two years, and with increasing focus to specific program goals. The Space Exploration Initiative touches virtually every scientific field and engineering discipline. The Outreach Program should be extended to include all other entities that are affected by the program in addition to the aerospace industry. An informed public is vital to the Space Exploration Initiative, which will require a sustained commitment of the nation's resources.

Why Now?

America stands at the threshold. Our national space program is undergoing intense scrutiny. Many ask questions similar to those voiced during the heyday of Apollo — What is the point of large space ventures? How can we afford the great expenditures? What is the function of a human presence in space?

By offering direction and purpose, the Space Exploration Initiative will rejuvenate our sense of challenge, of competitiveness, and of national pride. The Space Exploration Initiative is a positive, social endeavor. In a world of uncertainty, it has the capacity to inspire people, to stimulate them and to cause them to reach deep inside to find the very best they have to offer.

Technology development and architecture analysis must precede any final concept validation effort. The Initiative can be started now with a modest commitment of funds.

Great nations have always explored and profited from new frontiers and territories. Space is the new frontier of the industrialized world in the 21st century. Benefits from space and the technologies needed to journey there become increasingly important in the next century. As Americans, we must ask ourselves what our role will be in human exploration of the Solar System: to lead, follow or step aside?

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[1] The Advisory Committee on the Future of the U.S. Space Program.

[2] These recommendations are consistent with and expand upon those made by the Advisory Committee on the Future of the U.S. Space Program.