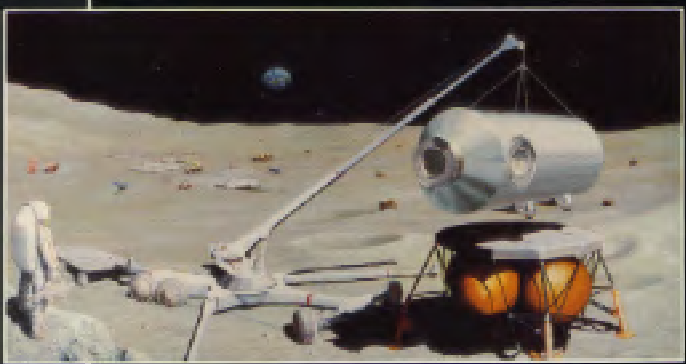
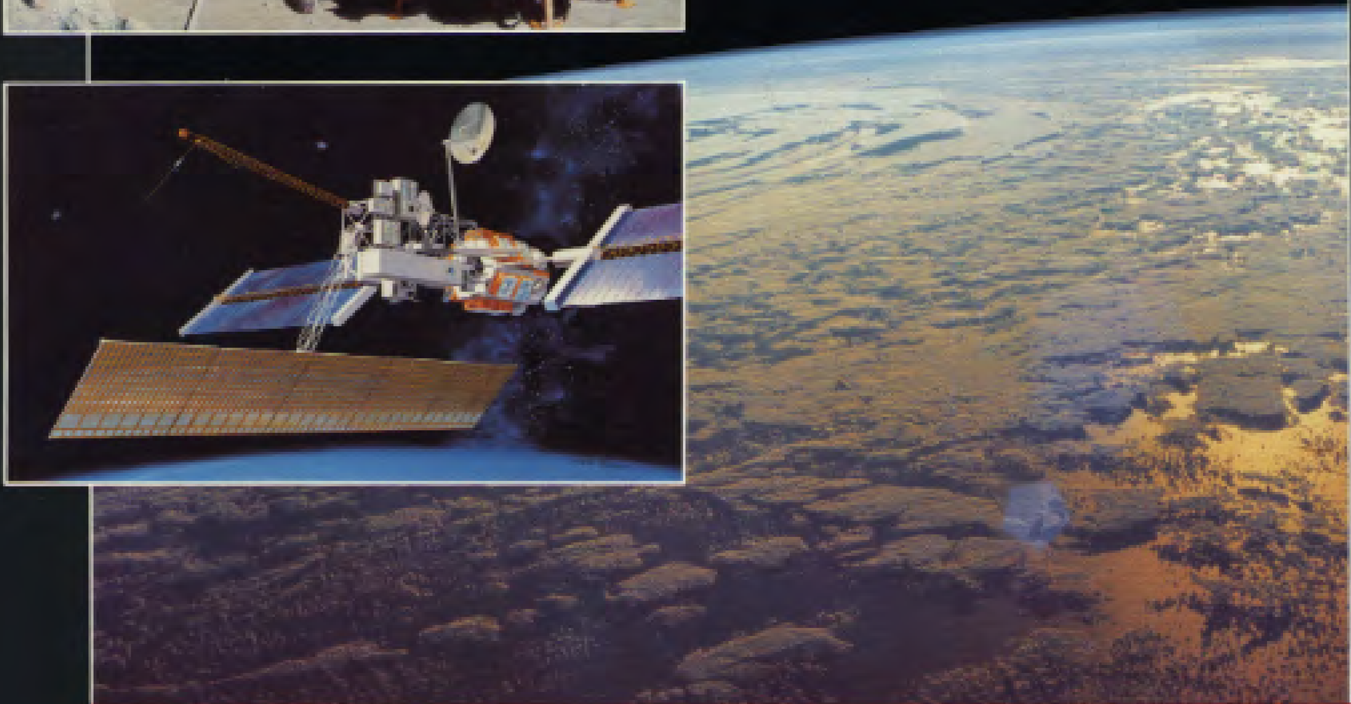
NASA

LEADERSHIP

and America's Future in Space





LEADERSHIP

and America's Future in Space

A Report to the Administrator
By Dr. Sally K. Ride
August 1987

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PREFACE

For nearly a quarter of a century, the U.S. space program enjoyed what can appropriately be termed a "golden age." From the launch of Earth-orbiting satellites, to the visits by robotic spacecraft to Venus and Mars, to the stunning achievement of landing the first human beings on the Moon, the many successes of the space program were exciting and awe-inspiring. The United States was clearly and unquestionably the leader in space exploration, and the nation reaped all the benefits of pride, international prestige, scientific advancement, and technological progress that such leadership provides.

However, in the aftermath of the *Challenger* accident, reviews of our space program made its shortcomings starkly apparent. The United States' role as the leader of spacefaring nations came into serious question. The capabilities, the direction, and the future of the space program became subjects of public discussion and professional debate.

The U.S. civilian space program is now at a crossroads, aspiring toward the visions of the National Commission on Space but faced with the realities set forth by the Rogers Commission. NASA must respond aggressively to the challenges of both while recognizing the necessity of maintaining a balanced space program within reasonable fiscal limits.

Two fundamental, potentially inconsistent views have emerged. Many people believe that NASA should adopt a major, visionary goal. They argue that this would galvanize support, focus NASA programs, and generate excitement. Many others believe that NASA is already overcommitted in the 1990s; they argue that the space agency will be struggling to operate the Space Shuttle and build the Space Station, and could not handle another major program.

Both views reflect concern over the current status of the space program, but each deals with only one aspect of the problem. The space program needs a long-range direction; it also needs the fundamental capabilities that would enable it to move in that direction. A single goal is not a panacea—the problems facing the space program must be met head-on, not oversimplified. But if there are no goals, or if the goals are too diffuse, then there is no focus to the program and no framework for decisions.

The goals of the civilian space program must be carefully chosen to be consistent with the national interest and also to be consistent with NASA's capabilities. NASA alone cannot set these goals, but NASA must lead the discussion, present technically feasible options, and implement programs to pursue those goals which are selected.

We must ask ourselves: "Where do we want to be at the turn of the century?" and "What do we have to do now to get there?" Without an eye toward the future, we flounder in the present. It is not too early to crystallize our vision of the space program in the year 2000. A clear vision provides a framework for current and future programs: it enables us to know which technologies to pursue, which launch vehicles to develop, and which features to incorporate into our Space Station as it evolves.

Leadership in space does not require that the U.S. be preeminent in all areas of space enterprise. The widening range of space activities and the increasing number of spacefaring nations make it virtually impossible for any country to dominate in this way. It is, therefore, essential for America to move promptly to determine its priorities and to pursue a strategy which would restore and sustain its leadership in the areas deemed important.

The Rogers Commission, in its concluding thoughts, states that NASA "constitutes a national resource that plays a critical role in space exploration and development. It also provides a symbol of national pride and technological leadership. The Commission applauds NASA's spectacular achievements of the past and anticipates impressive achievements to come." Only with a clear strategy in place, and its goals for the future defined and developed, will the country be able to regain and retain leadership in space.

INTRODUCTION

In response to growing concern over the posture and long-term direction of the U.S. civilian space program, NASA Administrator Dr. James Fletcher formed a task group to define potential U.S. space initiatives, and to evaluate them in light of the current space program and the nation's desire to regain and retain space leadership. The objectives of the study were to energize a discussion of the long-range goals of the civilian space program and to begin to investigate overall strategies to direct that program to a position of leadership.

The task group identified four candidate initiatives for study and evaluation. Each builds on NASA's achievements in science and exploration, and each is a bold, aggressive proposal which would, if adopted, restore the United States to a position of leadership in a particular sphere of space activity. The four initiatives are: (1) Mission to Planet Earth, (2) Exploration of the Solar System, (3) Outpost on the Moon, and (4) Humans to Mars. All four initiatives were developed in detail, and the implications and requirements of each were assessed.

This process was not intended to culminate in the selection of one initiative and the elimination of the other three, but rather to provide four concrete examples which would catalyze and focus the discussion of the goals and objectives of the civilian space program and the efforts required to pursue them.

When this activity began, several studies relevant to NASA's long-range goals and its ability to achieve those goals were already in progress. Some of these studies were being conducted by agencies external to NASA; others were internal NASA studies. This task group became familiar with those efforts, and sponsored others in areas not already covered. Additional information on all these studies is provided at the end of this report. The interested reader is referred to the published reports for detailed recommendations.

The major milestones of all relevant studies were plotted on a timeline, shown in **Figure 1**. This proved to be a useful summary for identifying the activities and their projected completion dates. A similar overview timeline should continue to be produced and revised, since it raises awareness of existing studies and coordinates related efforts.

This is not a final report. Rather, it is a status report describing the work accomplished to date, and how this work will continue. The report discusses long-term goals of the civilian space program, current posturing required to attain these goals, and the need for a continuing process to define, refine, and assess both the goals and the strategy to achieve them.

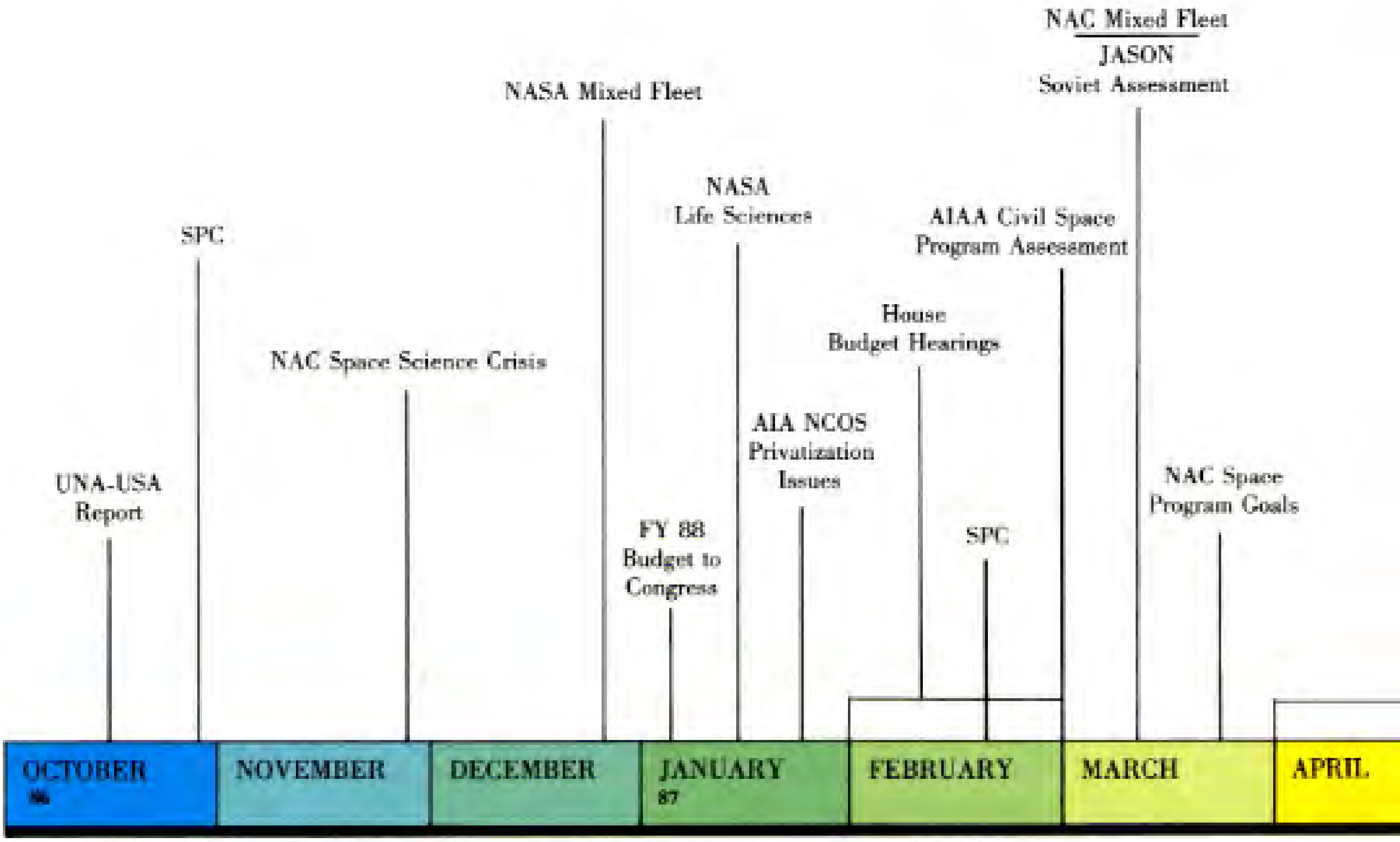
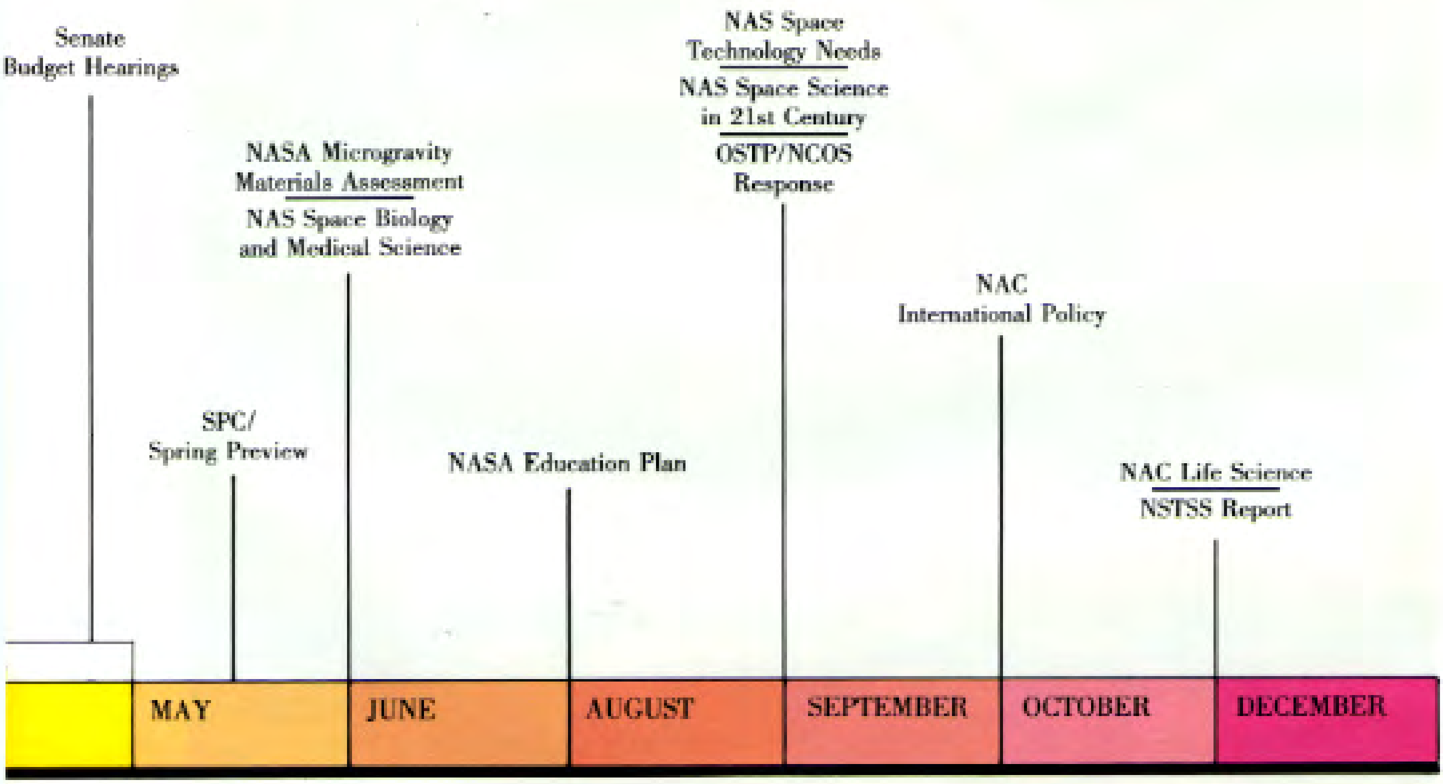
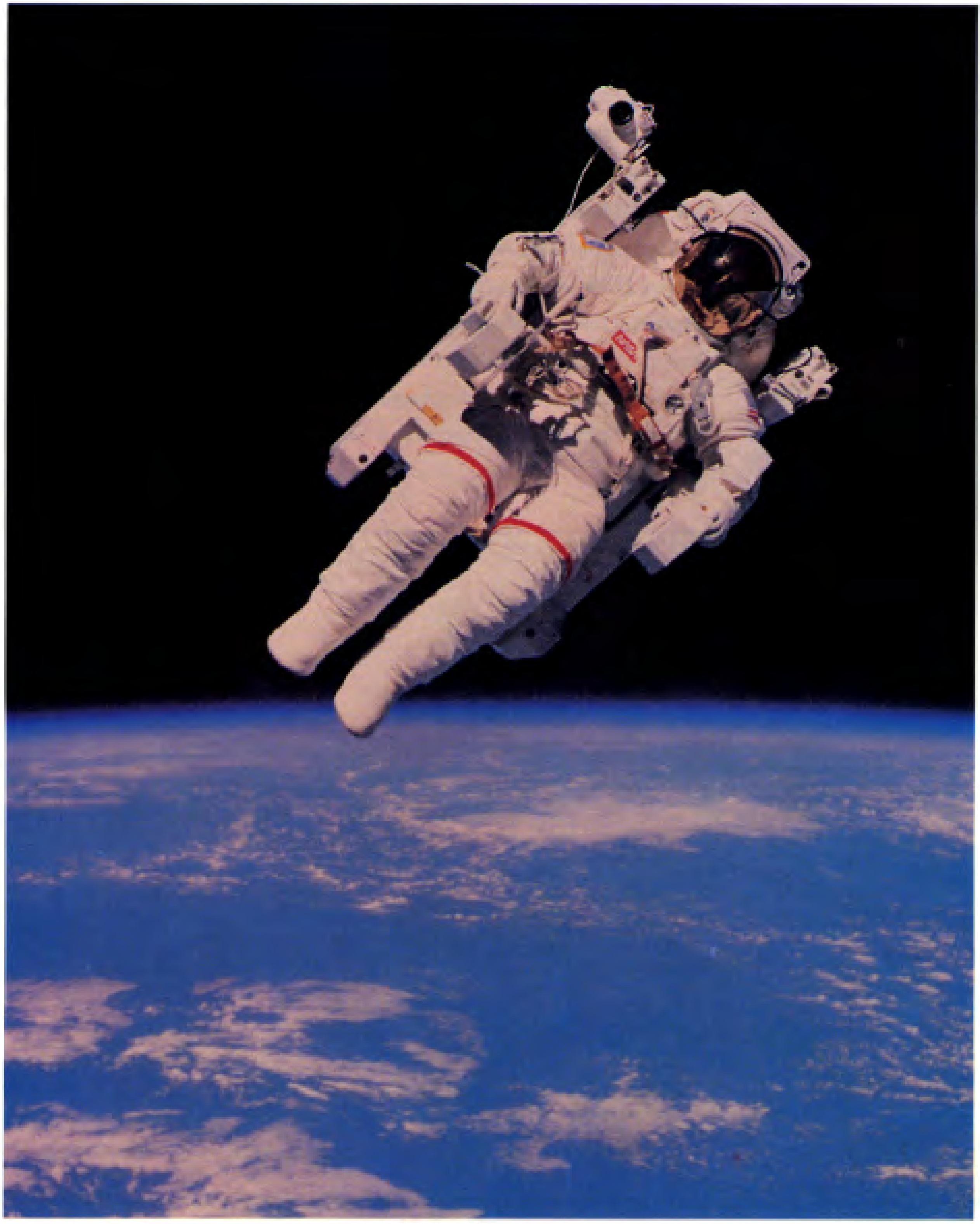


Figure 1. NASA Strategic/Long-Range Planning Activities

UNA-USA	United Nations Association of the United States of America
SPC	Strategic Planning Council
NAC	NASA Advisory Council
AIA	Aerospace Industries Association of America, Inc.
NCOS	National Commission on Space
AIAA	American Institute of Aeronautics and Astronautics
NAS	National Academy of Sciences
OSTP	Office of Science and Technology Policy
NSTSS	National Space Transportation and Support Study





LEADERSHIP IN SPACE

For two decades, the United States was the undisputed leader in nearly all civilian space endeavors. However, over the last decade the United States has relinquished, or is relinquishing, its leadership in certain critical areas; one such area is the exploration of Mars. With the *Mariner* and *Viking* missions in the 1960s and 1970s, this country pioneered exploration of Mars – but no American spacecraft has visited that planet since 1976. Our current plans for future exploration of Mars include only the *Mars Observer* mission, to be launched in 1992. In contrast, the Soviets have announced a program of extensive robotic exploration of the Martian surface, beginning in 1988 and extending through the 1990s.

The Soviets are now the sole long-term inhabitants of low-Earth orbit. The first, and only, U.S. space station, *Skylab*, was visited by three crews of astronauts before it was vacated in 1974; the U.S. has had no space station since. The Soviets have had eight space stations in orbit since the mid-1970s. The latest, *Mir*, was launched in 1986 and could accommodate cosmonauts and scientific experiments for nearly a decade before the U.S. Space Station can accommodate astronauts in 1995.

The United States has clearly lost leadership in these two areas, and is in danger of being surpassed in many others during the next several years.

The National Space Policy of 1982, which "establishes the basic goals of United States policy," includes the directive to "maintain United States space leadership." It further specifies that "the United States is fully committed to maintaining world leadership in space transportation," and that the civilian space program "shall be conducted ... to preserve the United States leadership in critical aspects of space science, applications, and technology."

Leadership cannot simply be proclaimed – it must be earned. As NASA evaluates its goals and objectives within the framework of the National Space Policy, the agency must first understand what is required to "maintain U.S. space leadership," since that understanding will direct the selection of national objectives.

Leadership does not require that the U.S. be preeminent in all areas and disciplines of space enterprise. In fact, the broad spectrum of space activities and the increasing number of spacefaring nations make it virtually impossible for any nation to dominate in this way. Being an effective leader does mandate, however, that this country have capabilities which enable it to act independently and impressively when and where it chooses, and that its goals be capable of inspiring others – at home and abroad – to support them. It is essential for this country to move promptly to determine its priorities and to make conscious choices to pursue a set of objectives which will restore its leadership status.

Leadership results from both the capabilities a country has acquired and the active demonstration of those capabilities; accordingly, the United States must have, and also be perceived as having, the ability to meet its goals and achieve its objectives.

A U.S. space leadership program must have two distinct attributes. First, it must contain a sound program of scientific research and technology development – a program that builds the nation's understanding of space and the space environment, and that builds its capabilities to explore and operate in that environment. The United States will not be a leader in the 21st Century if it is dependent on other countries for access to space or for the technologies required to explore the space frontier. Second, the program must incorporate visible and significant accomplishments; the United States will not be perceived as a leader unless it accomplishes feats which demonstrate prowess, inspire national pride, and engender international respect and a worldwide desire to associate with U.S. space activities.

National pride and international prestige are two natural benefits of leadership in space. National pride grows as citizens recognize their country's abilities and achievements; international prestige rises as other nations recognize those abilities and achievements.

Perhaps most significant, leadership is also a process. That process involves selecting and enunciating priorities for the civilian space program and then building and maintaining the resources required to accomplish the objectives defined within those priorities. NASA can contribute to this process by: (1) establishing a vision and goals consistent with national space interests; (2) developing and recommending objectives and programs that support those goals; (3) articulating, promoting, and defending them in the political and fiscal arenas; and (4) effectively executing approved programs.

To this end, NASA embarked last fall on a review of its goals and objectives. As NASA Administrator Dr. James Fletcher stated, "It is our intent that this process produce a blueprint to guide the United States to a position of leadership among the spacefaring nations of Earth."

The first step in this necessarily lengthy process was taken by NASA Senior Management's Strategic Planning Council when it adopted the statement in the box on the next page.

This statement reflects the belief that NASA embodies the human spirit's desire to discover, to explore, and to understand. It should be noted that the Space Shuttle and Space Station are not viewed as ends in themselves, but as the means toward achieving the broader goals of the nation's space program. Transportation and orbital facilities support and enable our efforts in science, exploration, and enterprise.

The next step in this process should be to articulate specific objectives and to identify the programs required to achieve these objectives. Of course, in some areas of study the programs have already been identified and are well under way. For example, The Hubble Space Telescope, a general-purpose astronomical observatory in space, is an element of NASA's program to increase our understanding of the universe in which we live; the redesign and requalification of the Space Shuttle's solid rocket booster joint is part of NASA's program to return the Space Shuttle to flight status. However, in other areas, such as piloted exploration, our objectives have not been clearly identified. Does this country intend to establish a lunar outpost? To send an expedition to Mars? What are NASA's major objectives for the late 20th and early 21st Centuries? The Space Shuttle and Space Station will clearly support the objectives, but what will they be supporting?

These questions cannot, of course, be answered by NASA alone. But NASA should lead the discussion, propose technically feasible options, and make thoughtful recommendations. The choice of objectives will shape, among other things, NASA's technology program, the evolution of the Space Station, and the character of Earth-to-orbit transportation.

MEETING THE CHALLENGE IN AERONAUTICS AND SPACE

NASA's vision is to be at the forefront of advancements in aeronautics, space science, and exploration. To set our course into the 21st Century and bring this vision to reality, NASA will pursue major goals which represent its aspirations in aviation and space. These goals are:

- Advance scientific knowledge of the planet Earth, the solar system, and the universe beyond.
- Expand human presence beyond the Earth into the solar system.
- Strengthen aeronautics research and develop technology toward promoting U.S. leadership in civil and military aviation.

Successful pursuit of these major goals requires commitment to the following supporting goals:

- Return the Space Shuttle to flight status and develop advanced space transportation capabilities.
- Develop facilities and pursue science and technology needed for the Nation's space program.

As NASA pursues these goals, we will:

- Promote domestic application of aerospace technologies to improve the quality of life on Earth and to extend human enterprise beyond Earth.
- Conduct cooperative activities with other countries when such cooperation is consistent with our national space goals.


UNITED STATES
UNITED

STRATEGIC OPTION DEVELOPMENT

The statement adopted by the Strategic Planning Council describes NASA's mission, its vision, and the scope of its activities. But the next step in the process cannot be taken in the absence of a comprehensive strategy for the civilian space program. Without a coherent formulation of the United States' intentions and priorities, there is no context in which to evaluate the relevance or the importance of any proposed initiatives.

To lay the foundation for the definition and articulation of such a strategy, NASA is currently developing a process to systematically assess the posture of our space program and to refine and assess candidate strategies to direct its future. This process, strategic option development, is still in its early stages; nevertheless, the development of the process has yielded some interesting insights into existing and potential space strategies.

The application of strategic option development to charting the future of the U.S. space program initially evolved from analogies drawn from relevant aspects of business theory. Although it is unconventional to think of space endeavors in terms of a business, many concepts from the business world are applicable and quite useful.

Leadership in business is possible at any time during a product's life cycle. When a new product is introduced (the innovator stage) there is no competition. If the product is successful, the firm becomes the market leader by default. The drawback, of course, is that innovators must accept the high cost and high risk associated with being first. The space program in the early 1960s was an innovator's market. Nearly every successful effort produced a "first," but the risks, as well as the number of failures, were very high.

The launch of America's first astronaut in space, Alan B. Shephard Jr., on the Mercury Redstone II from Cape Canaveral on May 5, 1961.

In a mature business market (the late majority stage) there exists a balance, as many firms compete for some share of the market. At this stage, it is still possible to be a market leader by carving out a particular niche of that market or by delivering the highest quality or best value. The launch vehicle market, for example, is approaching a more mature stage, and many countries will be vying for leadership in the 1990s.

A firm engaged in more than one market must develop an integrated strategy which provides the flexibility to be both an innovator in a new market and the leading competitor in a mature market; this principle should be applied to a space program as well.

The business of space has expanded considerably since the 1960s. The areas of scientific research, space technology, space exploration, and space services are still open to leadership through innovation, but some are also now open to leadership in more mature markets. In fact, national space programs must now look at four stages of space leadership: (1) the *pioneer* stage, innovation in some particular area of research, technology, or exploration; (2) the *complex second* stage, a continuation of a pioneering effort, but with broader, more complex objectives; (3) the *operational* stage, with relatively mature and routine capabilities; and (4) the *commercially viable* stage, with the potential for profit-making.

The activities of a space program can be characterized by physical regions of space: (1) deep space, (2) the outer solar system (the planets beyond the asteroid belt), (3) the inner solar system (the inner planets, the Moon, and the Sun), (4) high-Earth orbit, and (5) low-Earth orbit. Supporting technologies, such as launch capabilities and orbital facilities, are required to undertake all programs.

The complex concept of space leadership may be broken down into logical elements to form a two-dimensional matrix. The columns of the matrix are delineated by the four leadership stages outlined previously; the rows are the five physical regions of possible space activities, with a sixth row for supporting technologies and transportation. Each square of the matrix defines a particular area of possible leadership.

This matrix analysis provides a way to conceptualize alternative courses of action and can be used to describe and assess the space programs of spacefaring nations. It is possible to be a leader in a single square through any of a number of different programs. **Figure 2** illustrates several programs which, if undertaken in the 1990s, would result in leadership in one area of space endeavor. For example, a country could be a leader in the highlighted area of a complex second effort in the inner solar system by successfully establishing a lunar outpost or by sending sophisticated rovers to other worlds.

Not all the squares will be accessible in the next decades. Technology has not progressed to the point that any nation is able to contemplate, for example, commercial prospects in the outer solar system. This figure does not represent a particular strategy; rather, it represents a collection of potential programs.

Being a leader in one area no longer results in overall space leadership. In the early 1960s, the United States and the Soviet Union were the only competitors, and only the cells in the lower left corner of the matrix were accessible. As technology advanced and nations gained experience in space, the opportunities began to expand. In the 1960s, the U.S. learned to send satellites to geosynchronous orbit, scientific experiments to low-Earth orbit, spacecraft to Mars, and even astronauts to the Moon. America was undeniably the leader in space exploration, but the range of space activities was (by today's standards) relatively limited. In the 1980s, not only has the number of spacefaring nations increased, but so has the range of activities that an interested nation might undertake.

The business of space has expanded and branched, and now encompasses such diverse and mature fields as remote sensing, microgravity materials research, commercial communications, and interplanetary exploration. It appears virtually impossible for a single nation to dominate in all space endeavors. Since the U.S. can no longer reasonably expect to lead the way in all activities, it is now important to adopt a strategy to strive for leadership in carefully chosen areas.

If nations engage in similar activities (occupy the same space on the matrix) the conditions exist for either rivalry or cooperation; if a nation engages in distinct activities (occupies a space alone), the conditions exist for uncontested leadership.

This matrix was used to broadly characterize the space programs of the United States and other spacefaring nations during two periods of the space age: (1) 1957 through 1977, illustrated by **Figure 3**; and (2) 1978 through 1990, illustrated by **Figure 4**.

The major programs, U.S. and non-U.S., were identified and placed in the appropriate squares. This is by no means a comprehensive compilation, but the selected activities are representative of space efforts during these periods. An admittedly subjective assessment was made of whether the public perceived the U.S. or non-U.S. efforts to be the leaders in a given square. Each square was then shaded either blue or red: blue if the U.S. was judged the leader, red if not.

A comparison of the two matrices graphically displays the difference between these two periods of time. In the early years of the space age, fewer areas were accessible and the U.S. was the clear leader in most; the matrix representing the 1980s illustrates the decline of U.S. leadership.

REGION OF SPACE / LEADERSHIP STAGE	PIONEER	COMPLEX SECOND	OPERATIONAL	COMMERCIALLY VIABLE
DEEP SPACE	STAR PROBE	LUNAR OBSERVATORY		
OUTER SOLAR SYSTEM	NEPTUNE FLYBY-PROBE	CASSINI		
INNER SOLAR SYSTEM	MARS SAMPLE RETURN HUMAN EXPEDITION TO MARS	AUTOMATED ROVERS LUNAR OUTPOST	LUNAR BASE	
HIGH-EARTH ORBIT	LARGE SPACE STRUCTURES	ROBOTIC SERVICING	SPACE TRANSFER VEHICLE	SOLAR POWER SATELLITES
LOW-EARTH ORBIT	VARIABLE-G FACILITY	EARTH OBSERVING PLATFORMS	ON-ORBIT ASSEMBLY	MATERIALS PROCESSING
SUPPORTING TECHNOLOGIES AND TRANSPORTATION	NATIONAL AEROSPACE PLANE	SHUTTLE II	ASSURED ACCESS AND RETURN	COMMERCIAL LAUNCH VEHICLES

Figure 2. Possible Programs to Capture Leadership after 1995

Examining the programs of the spacefaring nations shows the basic character of each. The U.S. space program has historically been composed of pioneering efforts – significant firsts and complex second efforts, which emphasized advanced research, technology, and exploration. The general trend can be characterized as revolutionary, producing spectacular events, rather than moderate, evolutionary advances. Even the United States Space Shuttle, though designed to be operational, was a revolutionary concept – it did not evolve from existing launch vehicles.

The Soviet space program, which is radically different from the American program, can be characterized as systematic and evolutionary. The primary focus is not on advanced research and technology, but on incrementally developed operational capabilities, achieved through a strong commitment to a robust infrastructure. The Soviets have steadily evolved toward this operational state and they are now beginning to build on that operational base to move slowly into the commercial arena.

The Europeans and the Japanese appear to be pursuing strategies that combine desires to pursue science in selected areas and to achieve commercial viability in others. The launch system Ariane, the remote-sensing satellite SPOT, and the Japanese JEM (which will be devoted to materials science research) are all examples of elements in these strategies.

These observations suggest that there is no one "correct" strategy; rather, there are many distinct strategic options. Clearly, each nation should choose and pursue a strategy which is consistent with its own national objectives.

What should our choice be? Do we want to mature our operational Earth-orbiting capabilities to a viable commercial enterprise? Should we continue our leadership role in solar system and deep-space exploration? Or should we focus on venturing ever further outward from Earth with human expeditions to the planets?

REGION OF SPACE / LEADERSHIP STAGE	PIONEER	COMPLEX SECOND	OPERATIONAL	COMMERCIALLY VIABLE
DEEP SPACE	ORBITING ASTRONOMICAL OBSERVATORY–2 HIGH-ENERGY ASTRONOMY OBSERVATORY–1			
OUTER SOLAR SYSTEM	PIONEER			
INNER SOLAR SYSTEM	MARINER SURVEYOR 3 ISEE LUNA APOLLO 8, 11 HELIOS VENERA VIKING 1	SURVEYOR 1 APOLLO 15 ZOND 3		
HIGH-EARTH ORBIT	SYNCOM 1,2,3 CTS INTELSAT	APPLICATIONS TECHNOLOGY SATELLITE	EARLY BIRD INTELSAT	WESTAR INTELSAT INTERSPUTNIK INMARSAT
LOW-EARTH ORBIT	ECHO 1 TIROS ARIEL 1 SPUTNIK GEMINI VOSTOK 1 LANDSAT	EXPLORER 1 SOYUZ 4, 5 GEMINI APOLLO/SOYUZ	TIROS 5	
SUPPORTING TECHNOLOGIES AND TRANSPORTATION	SATURN 5 SALYUT 1	SKYLAB SALYUT		

*Programs for which the U.S. is not primarily responsible are indicated by italics; areas in which no leadership is perceived are without color

Figure 3. Leadership Matrix: Representative Achievements, 1957 to 1977

REGION OF SPACE / LEADERSHIP STAGE	PIONEER	COMPLEX SECOND	OPERATIONAL	COMMERCIALLY VIABLE
DEEP SPACE	HUBBLE SPACE TELESCOPE MIR KVANT MODULE INFRARED ASTRONOMICAL SATELLITE			
OUTER SOLAR SYSTEM	VOYAGER	GALILEO		
INNER SOLAR SYSTEM	INTERNATIONAL COMET EXPLORER HALLEY FLOTILLA	MAGELLAN VENERA ULYSSES PHOBOS VEGA	VENERA	
HIGH-EARTH ORBIT		GLOBAL POSITIONING SATELLITE INERTIAL UPPER STAGE GLONASS	PAYLOAD ASSIST MODULE GLOBAL POSITIONING SATELLITE TDRS	COMMUNICATION SATELLITES INTELSAT
LOW-EARTH ORBIT		SATELLITE REPAIR SALYUT SPACELAB	MIR SALYUT	LANDSAT SPOT
SUPPORTING TECHNOLOGIES AND TRANSPORTATION	STS 1 THROUGH 4 USSR SHUTTLE	STS ENERGIA H-1 ARIANE 4	TITAN IV PROTON PROGRESS	ATLAS/CENTAUR ARIANE TITAN 3HD PROTON 3 DELTA LONG MARCH

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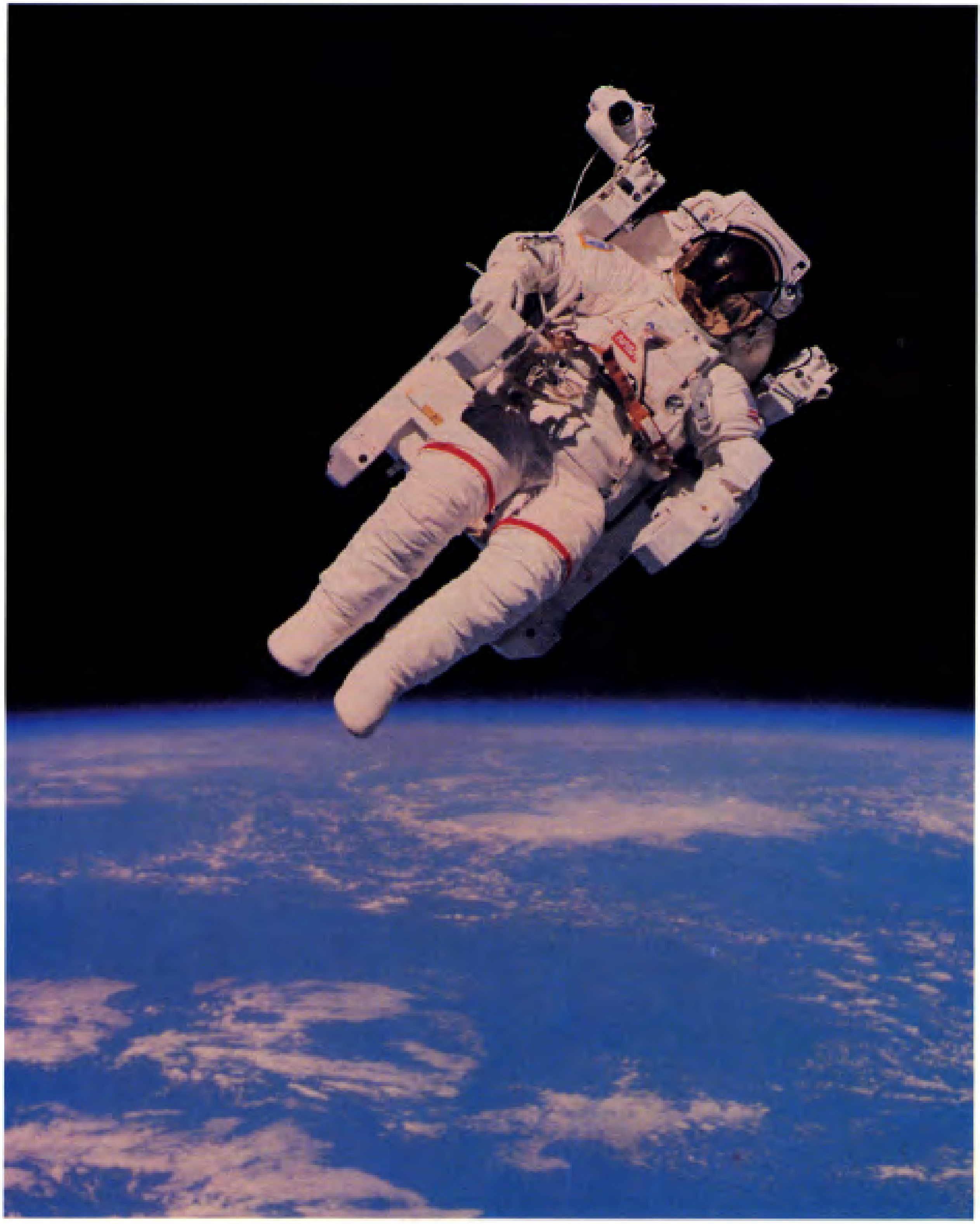
Figure 4. Leadership Matrix: Representative Achievements, 1978 to 1990



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Leadership cannot simply be proclaimed – it must be earned. As NASA evaluates its goals and objectives within the framework of the National Space Policy, the agency must first understand what is required to "maintain U.S. space leadership," since that understanding will direct the selection of national objectives.

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A U.S. space leadership program must have two distinct attributes. First, it must contain a sound program of scientific research and technology development – a program that builds the nation's understanding of space and the space environment, and that builds its capabilities to explore and operate in that environment. The United States will not be a leader in the 21st Century if it is dependent on other countries for access to space or for the technologies required to explore the space frontier. Second, the program must incorporate visible and significant accomplishments; the United States will not be perceived as a leader unless it accomplishes feats which demonstrate prowess, inspire national pride, and engender international respect and a worldwide desire to associate with U.S. space activities.

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The first step in this necessarily lengthy process was taken by NASA Senior Management's Strategic Planning Council when it adopted the statement in the box on the next page.

This statement reflects the belief that NASA embodies the human spirit's desire to discover, to explore, and to understand. It should be noted that the Space Shuttle and Space Station are not viewed as ends in themselves, but as the means toward achieving the broader goals of the nation's space program. Transportation and orbital facilities support and enable our efforts in science, exploration, and enterprise.

The next step in this process should be to articulate specific objectives and to identify the programs required to achieve these objectives. Of course, in some areas of study the programs have already been identified and are well under way. For example, The Hubble Space Telescope, a general-purpose astronomical observatory in space, is an element of NASA's program to increase our understanding of the universe in which we live; the redesign and requalification of the Space Shuttle's solid rocket booster joint is part of NASA's program to return the Space Shuttle to flight status. However, in other areas, such as piloted exploration, our objectives have not been clearly identified. Does this country intend to establish a lunar outpost? To send an expedition to Mars? What are NASA's major objectives for the late 20th and early 21st Centuries? The Space Shuttle and Space Station will clearly support the objectives, but what will they be supporting?

These questions cannot, of course, be answered by NASA alone. But NASA should lead the discussion, propose technically feasible options, and make thoughtful recommendations. The choice of objectives will shape, among other things, NASA's technology program, the evolution of the Space Station, and the character of Earth-to-orbit transportation.

MEETING THE CHALLENGE IN AERONAUTICS AND SPACE

NASA's vision is to be at the forefront of advancements in aeronautics, space science, and exploration. To set our course into the 21st Century and bring this vision to reality, NASA will pursue major goals which represent its aspirations in aviation and space. These goals are:

- Advance scientific knowledge of the planet Earth, the solar system, and the universe beyond.
- Expand human presence beyond the Earth into the solar system.
- Strengthen aeronautics research and develop technology toward promoting U.S. leadership in civil and military aviation.

Successful pursuit of these major goals requires commitment to the following supporting goals:

- Return the Space Shuttle to flight status and develop advanced space transportation capabilities.
- Develop facilities and pursue science and technology needed for the Nation's space program.

As NASA pursues these goals, we will:

- Promote domestic application of aerospace technologies to improve the quality of life on Earth and to extend human enterprise beyond Earth.
- Conduct cooperative activities with other countries when such cooperation is consistent with our national space goals.


USA

PROGRAMMATIC ASSESSMENT

Each of the initiatives described in the previous section is a worthwhile program. Although each has something different to offer, each falls within the framework of NASA's vision, each builds on and extends existing capabilities, and each elicits the reaction, "America ought to be doing this." In the absence of fiscal and resource constraints, the United States would undoubtedly adopt all four. In the presence of those very real constraints, and the additional constraints imposed by the current state of our civilian space program, this course of action is not possible.

In its desire to revitalize the civilian space program, NASA must avoid the trap identified by the Rogers Commission during its investigation of the *Challenger* accident: "The attitude that enabled the agency to put men on the moon and to build the Space Shuttle will not allow it to pass up an exciting challenge – even though accepting the challenge may drain resources from the more mundane (but necessary) aspects of the program." The Commission further observed (in reference to the Shuttle flight rates): "NASA must establish a realistic level of expectation, then approach it carefully."

To establish a realistic level of expectation, NASA must consider the current condition of the space program, its strengths and limitations, and its capabilities for growth. Any bold initiative has to begin with and then build on today's space program, which unfortunately lacks some fundamental capabilities. For example, our most critical commodity, Earth-to-orbit transportation, is essential to each of the initiatives. But the Space Shuttle is grounded until at least June of 1988, and when it does return to flight status, the flight rate will be considerably lower than that projected before the *Challenger* accident (a four-Shuttle fleet is estimated to be capable of 12 to 14 flights per year).

In hindsight, it is easy to recognize that it was a crippling mistake to decree that the Space Shuttle would be this country's only launch vehicle. Several studies since the *Challenger* accident have recommended that the civilian space program include expendables in its fleet of launch vehicles. This strategy relieves some of the burden from the Shuttle, gives the country a broader, more flexible launch capability, and makes the space program less vulnerable in the event of an accident.

The problem of limited launch capability or availability will be magnified during the assembly and operation of the Space Station. Currently, NASA plans to use only the Space Shuttle to transport cargo and people to and from the Space Station. This places a heavy demand on the Shuttle (six to eight flights per year), but more important, it makes the Space Station absolutely dependent on the Shuttle. If Shuttle launches should be interrupted again in the mid-1990s, this nation must still have access to

TRANSPORTATION REQUIREMENTS

NASA transportation needs for the 1990s and beyond received considerable attention from the task group and committees examining agency goals and future program thrusts. The consensus of their findings is that if the Nation is to open a "Highway to Space," we must regain regular and assured access to space and expand launch capacity based on expendable and reusable vehicles.

"NASA should, on a most urgent basis, initiate a program to incorporate a diversified family of expendable launchers into its space flight program, to include a heavy-lift ELV. Payloads should be off-loaded from shuttle onto ELVs wherever possible." *Report of the Task Force on Issues of a Mixed Fleet*, 1987

"The U.S. should continue to expand its launch capacity based on a mixed fleet of expendable and reusable launch vehicles to preclude total reliance on any one launch system, so that the present manned and unmanned launchers will remain operationally healthy until the next generation of vehicles is fully developed." *U.S. Civil Space Program: An AIAA Assessment*, 1987

"The use of a mixed launch fleet will allow humans to fly when they are needed on a mission and allow unmanned vehicles to be the carrier of choice for other missions... Diversity will also allow a better matching of the scientific requirements of a mission with the launch capability needed to meet those requirements, rather than forcing the mission to meet the constraints of a single inflexible launch system." *The Crisis in Space and Earth Science*, 1986

"The shuttle fleet will become obsolescent by the turn of the century. Reliable, economical launch vehicles will be needed to provide flexible, routine access to orbit for cargo and passengers at reduced costs ... to reduce space operation costs as soon as possible, the Commission recommends that three major space transport needs be met in the next 15 years: cargo transport to low Earth orbit; passenger transport to and from low Earth orbit; and round-trip transfer beyond low Earth orbit." *Pioneering the Space Frontier*, 1986 space and the means to transport cargo and people to and from the Space Station. The importance of this capability was emphasized by the National Commission on Space in its report, *Pioneering the Space Frontier*: "Above all, it is imperative that the US maintain a continuous ability to put both humans and cargo into orbit."

From now until the mid-1990s, Earth-to-orbit transportation is NASA's most pressing problem. A space program that can't get to orbit has all the effectiveness of a navy that can't get to the sea. America must develop a cadre of launch vehicles that can first meet the near-term commitments of the civilian space program and then grow to support projected programs or initiatives.

Expendable launch vehicles should be provided for payloads which are not unique to the Space Shuttle – this is required just to implement current plans and to satisfy fundamental requirements.

A Shuttle-derived cargo vehicle should be developed immediately. A Shuttle-derived vehicle is attractive because of its lift capacity, its synergism with the Space Transportation System, and its potential to be available for service in the early 1990s. This cargo vehicle would reduce the payload requirements on the Shuttle for Space Station support and would accelerate the Space Station assembly sequence.

The United States should also seriously consider the advisability of a crew-rated expendable to lift a crew capsule or a logistics capsule to the Space Station. The logistics vehicle, for Space Station resupply and/or instrument return, would be developed with autodocking and precision reentry capabilities. The crew capsule would carry only crew members and supplies, would launch (with or without a crew) on the expendable vehicle, would have autodocking capability, and might also be used for crew rescue.

TECHNOLOGY

Rebuilding the Nation's technology base is essential for the successful achievement of any long-term space goal. It is widely agreed that we are living off the interest of the *Apollo* era technology investment, and that it is time to replenish our technology reservoir in order to enhance our range of technical options.

"The Nation has allowed its technology base to erode, leaving it with little capability to move out in new directions should the need arise." Letter from Daniel J. Fink (Chairman, NASA Advisory Council) to James Fletcher, dated August 14, 1986

"Space technology advancement underlies any comprehensive future space activity. The present course is a status-quo caretaker path with no potential growth. New commitments are called for in key technologies such as propulsion, automation and robotics, flight computers, information systems, sensors, power generation, materials, structures, life support systems, and space processing. We support the recommendation by the National Commission on Space for a three-fold increase in this relatively low-budget but extremely important area of space technology advancement, especially in view of strong foreign commitments to such technology development." *U.S. Civil Space Program: An AIAA Assessment*, 1987

"Research must be pursued on a broad front, to identify and quantify technical possibilities before their usefulness can be judged. Such a research and technology program is therefore properly conceived as opportunity generating, not directed toward applications." *Pioneering the Space Frontier*, 1986

These transportation capabilities are required just to launch, assemble, operate, and safely inhabit the Space Station, and to have some prospect of being able to support future initiatives.

Without sound, reliable Earth-to-orbit transportation available to lift sensors, spacecraft, scientists, and explorers to orbit, we will not be in a position to aggressively pursue either science or exploration. We have stated that transportation is not our goal – but it is essential to the successful pursuit of whatever goals we choose. If we do not make a commitment now to rebuild and broaden our launch capability, we will not have the option of pursuing any of the four initiatives described in the previous section.

The same can be said for advanced technology. The National Commission on Space observed that "NASA is still living on the investment made [during the *Apollo* era], but cannot continue to do so if we are to maintain United States leadership in space." Several recent studies concur, concluding that our technology base has eroded and technological research and development are underfunded. The technology required for bold ventures beyond Earth's orbit has not yet been developed, and until it is, human exploration of the inner solar system will have to wait.

Technologies explored by Project Pathfinder.

Project Pathfinder has been developed by NASA's Office of Aeronautics and Space Technology in conjunction with experts on the Lunar and Mars initiatives. Pathfinder would provide the technologies to enable bold missions beyond Earth's orbit: technology for autonomous systems and robotics, for lunar and planetary advanced propulsion systems, and for extraction of useful materials from lunar or planetary sources. It also deals in a significant way with the human ability to live and work in space, by developing technologies for life-support systems and the human/machine interface. Until advanced technology programs like Project Pathfinder are initiated, the exciting goals of human exploration will always remain 10 to 20 years in the future.

Life sciences research is also critical to any programs involving relatively long periods of human habitation in space. Because the focus of our life sciences research for the last several years has been on Space Shuttle flights, which only last for five to ten days, there has been no immediate need for a program to study the physiological problems associated with longer flights. Without an understanding of the long-term effects of weightlessness on the human body, our goal of human exploration of the solar system is severely constrained.

Before astronauts are sent into space for long periods, research must be done to understand the physiological effects of the microgravity and radiation environments, to develop measures to counteract any adverse effects, and to develop medical techniques to perform routine and emergency health care aboard spacecraft.

Project Pacer, developed by NASA's Office of

Space Science and Applications, is a focused program designed to develop that understanding and provide the physiological and medical foundation for extended spaceflight. This research would be conducted in laboratories and on Space Shuttle missions in preparation for the critical long-term experiments to be conducted on the Space Station.

Until the Space Station is occupied, and actual long-duration testing is begun, we will lack the knowledge necessary to design and conduct piloted interplanetary flights or to inhabit lower-gravity surface bases. Although the research conducted prior to the occupation of Space Station cannot provide definitive answers to several key questions, it is an essential precursor to the research and technology development on the Space Station.

LIFE SCIENCES RESEARCH

The prospect of an extended human presence in space on the Space Station and later on extended missions to the Moon or Mars requires a commitment to better understand and respond to biomedical, psychological, and human engineering challenges. Although there is great confidence that we will eventually establish a presence on other bodies in the solar system, there remains uncertainty in the medical community about the implications of such journeys for human health, safety, and productivity. A number of recent studies highlight concerns and identify areas requiring additional research.

"Space medicine is unique in the context of the other space sciences – primarily because, in addition to questions of fundamental interest, there is a need to address those issues that are more of a clinical or human health and safety nature ... if this country is committed to a future of humans in space, particularly for long periods of time, it is essential that the vast number of uncertainties about the effects of microgravity on humans and other living organisms be recognized and vigorously addressed. Not to do so would be imprudent at best – quite possibly, irresponsible." *A Strategy for Space Biology and Medical Science*, 1987

"Many crucial issues in the three major areas of health, life support, and operational capabilities remain to be resolved before the safety of humans working in space over months and years can be assured. Certain aspects of physiological adaptation to microgravity may be life-threatening, especially over the long-term ... Areas such as medical care, radiation protection, environmental maintenance, and human productivity are equally serious, but the research and development activities associated with these areas have at least begun on a modest scale. To neglect any of these areas could prove risky, and parallel research activities are recommended." *Advanced Missions with Humans in Space*, 1987

"Of paramount practical importance are human safety and performance. Long-duration flights on the Space Station will increase our understanding of the effects of the space environment on people and other living systems. Problems of bone demineralization and loss of muscle mass persist, and effective empirical solutions are unlikely to be found soon ... It is imperative that basic research on this problem continue, both on the ground and in space." *Pioneering the Space Frontier*, 1986

Both technology development and life sciences research are pacing elements in human exploration.

The four initiatives represent widely varying levels of complexity and commitment. As part of the development and evaluation of the initiatives, an assessment was performed to estimate their relative complexities and therefore their relative impacts on the agency and its resources. The initiatives, and results from related studies, were reviewed to identify the required technology, transportation, on-orbit facilities, and precursor science. This assessment yielded the elements comprising each initiative – the building blocks of that initiative.

The assessment sought to define the initiatives to a reasonable level of detail through 2010. At this time, the initiatives would be in different stages of development. All Earth observing platforms would be in space with their observing systems operating; they would be serviced periodically, and would continue to transmit data to Earth for years. The final mission of the Planetary initiative would be complete; this initiative is not defined past 2010. The Lunar outpost would be well established, with most surface elements developed and delivered; it would receive continuing logistics support, but would be somewhat self sustaining, and have considerable potential for growth and for support of further exploration activities. In 2010, the nation's Mars program would have just finished its human reconnaissance phase, and would be prepared to embark on the establishment of an outpost.

To provide a common starting point for each initiative, this analysis assumed the currently planned NASA space program as a foundation. That is, each initiative must be built from the foundation of a fleet of four Space Shuttles and a Phase 1 Space Station; everything else that would have to be added to accomplish the initiative, including additional Space Station modules, new transportation elements, unscheduled precursor science missions, etc., was assumed to be part of that initiative.

Some of the elements of each initiative would be developed solely for that initiative; many others could be common to other intitiatives as well. An example of the former is the lunar oxygen plant designed to extract oxygen from the lunar soil. Although similar technologies might eventually be needed at a Mars outpost, the element itself exists only in the Lunar initiative. An example of an element which could be common to several programs is the space transfer vehicle of the Earth initiative. Although it would lift geostationary platforms from the Space Station to their final orbit, this vehicle could also be used to deliver other cargo (unrelated to the Earth initiative) to geosynchronous orbit, or it could be the basis of a lunar transfer vehicle. Each initiative has elements which could be

	PLANETARY	EARTH	LUNAR	MARS
• EARTH TO ORBIT VEHICLES				
- SPACE SHUTTLE	*	●	●	●
- PERSONNEL CARRIER			●	●
- HEAVY-LIFT LAUNCH VEHICLE	●	●	●	●
- EXPENDABLE LAUNCH VEHICLE	●	●	●	●
- SIGNIFICANT RETURNED CARGO			●	●
• SPACE TRANSFER VEHICLES				
- ORBITAL MANEUVERING VEHICLE	*	●	●	●
- CABIN			●	●
- TELEROBOTIC SERVICER		●	●	●
- EXPENDABLE UPPER STAGES	●	●	●	●
- GEOSTATIONARY TRANSFER VEHICLE		●		
- CARGO TRANSFER VEHICLE			●	●
- PERSONNEL TRANSFER VEHICLE			●	●

* REQUIRED TO RECOVER MARS SAMPLE

Table 1.
Transportation Requirements for the Initiatives

common to other programs, as well as initiative-specific elements.

An overview of the transportation elements required for the initiatives is shown in **Table 1**. The Earth and Planetary initiatives make the most modest demands on transportation, in terms of both essential new capabilities and frequency of use. But each of the initiatives requires an Earth-to-orbit transportation system comprised of more than just a Space Shuttle fleet.

A heavy-lift launch vehicle is either enabling, or significantly enhancing, to all the initiatives. A Shuttle-derived vehicle would have sufficient

SPACE STATION EVOLUTION

The Phase 1 Space Station will be a permanently staffed "laboratory in space" by 1996. Other capabilities, such as an assembly station or a fueling depot, will not be included in the initial phase, but could be accommodated later if a need for those functions is clearly identified.

A key question for the not-too-distant future is "How should the Space Station evolve?" Since the Space Station is a means to pursue our goals, the answer depends on what those goals are. It is important to understand what each initiative demands of the Space Station. For example, the Planetary initiative makes few demands on the Space Station; the Mars initiative makes substantial demands.

NASA's Office of Space Station has set up a Strategic Plans and Programs Division whose charter is to understand how the Space Station would be required to evolve under a variety of scenarios for the future, and what provisions must be made in the design of the Phase 1 Space Station to ensure that the evolution is possible.

Space Station evolution workshops, held in September 1985 and July 1986, laid the foundation for understanding how to accommodate a variety of users whose requirements may not be compatible. These workshops recognized, for example, that a laboratory in space, featuring long-term access to the microgravity environment, might not be compatible with an operational assembly and checkout facility, as construction operations could disturb the scientific environment.

Artist's conception of the Phase 1 Space Station.

Space Station evolution planning will include an assessment of the implications of each of the four initiatives. It is important to have specific scenarios, with a level of technical definition behind them, to serve as a basis for these assessments. It is also important that results from these assessments feed back into the initiative scenarios. This iterative approach is required to establish reasonable evolution scenarios and initiatives that are compatible with the proposed evolution.

capacity for the Earth and Planetary initiatives. It would also satisfy the requirements of the Mars and Lunar initiatives through the 1990s, although shortly after the turn of the century both would need a vehicle with a lift capacity of 150,000 to 200,000 pounds. This higher lift capacity is needed primarily to supply the large amounts of propellant required for each initiative (about 2.2 million pounds to low-Earth orbit for each Mars sprint mission; 200,000 pounds to low-Earth orbit for each lunar trek).

The Lunar and Mars initiatives also have a critical need for the capability to transport personnel to and from the Space Station. This need could be filled by a personnel module added to the Shuttle, or by some other personnel carrier. The additional crew members would perform on-orbit assembly of the cargo and crew vehicles. Although there is currently no good estimate of the size of the crew required to assemble and test a vehicle in orbit, it is likely that the Lunar initiative, if it develops as projected in Phase III, would require more than 30 people in low-Earth orbit by the year 2010. It builds to this peak gradually, though, and the early assembly requirements (2000 to 2005) can be phased in slowly.

All the initiatives have other needs as well. The Planetary initiative's needs are limited to expendable stages, and possibly an Orbital Maneuvering Vehicle for the recovery of a returned Mars sample. The Earth initiative makes more substantial use of Earth-orbital transportation, including a transfer vehicle to lift fully assembled observing platforms from the Space Station to geosynchronous orbit, and sophisticated Orbital Maneuvering Vehicles to aid in platform servicing. The Lunar and Mars initiatives are more demanding. Both are likely to require Orbital Maneuvering Vehicles to transport personnel from the Space Station to orbital assembly sites. Most significant, both require substantial space transfer vehicles to transport crews from low-Earth orbit to either the Moon or Mars. Although the lunar transfer vehicle could be a derivative of a transfer vehicle to geosynchronous orbit (or vice versa), at this time it appears that the Mars transfer vehicle will demand a different design.

The orbital facilities required for each initiative are shown in **Table 2**. The Planetary initiative has limited requirements in this area; the other three have extensive needs that begin with the Phase 1 Space Station. The Phase 1 Space Station includes polar platforms and attached payloads for the Earth initiative; it serves as a technology and systems test bed for the Lunar initiative; and it will be a crucial laboratory for life sciences research and technology development for the Mars initiative.

	PLANETARY	EARTH	LUNAR	MARS
• LOW-EARTH ORBIT FACILITIES				
-PHASE I SPACE STATION		●	●	●
-SPACE STATION ADDITIONS				
-LIFE SCIENCE RESEARCH				●
-SAMPLE ISOLATION	●			●
-SPACE TRANSFER VEHICLE ASSEMBLY AND OPERATIONS			●	●
-ADDITIONAL CREW			●	●
-PROPELLANT STORAGE			●	●
-POLAR PLATFORMS		●		
• GEOSTATIONARY FACILITIES				
-PLATFORMS		●		
-COMMUNICATIONS			●	●
• LUNAR FACILITIES				
-SERVICE STATION			●	
-COMMUNICATIONS			●	
• MARS FACILITIES				
-CARGO VEHICLE ORBITAL OPERATIONS				●

Table 2.
Orbital Facilities Required for the Initiatives

All the initiatives require that the Space Station evolve additional capabilities, but the needs of the Planetary initiative (a sample return module) and the Earth initiative (servicing capability, operation of a space transfer vehicle) are relatively modest. The Lunar initiative requires gradual evolution to support the assembly, servicing, and checkout of lunar transfer vehicles. This requires more people in orbit (and therefore more Space Station modules and logistics traffic), spaceport facilities, and a propellant depot. The Mars initiative also relies on those spaceport facilities and additional crew accommodations, and although it will not occur quite as soon as in the Lunar initiative, the assembly of the large Mars cargo and piloted vehicles will be a significant task.

The Lunar initiative includes significant surface facilities such as habitation modules, laboratory modules, and an oxygen plant; the Mars initiative looks toward an eventual outpost (after 2015), but while similar surface facilities would be necessary at that time, they have not been included in the assessment to 2010. The Lunar and Mars initiatives both require landers, ascent vehicles, and rovers. These would most likely use some common technologies and subsystems, but they would not be identical.

The initiatives also require investments in technology development, and investments in institutional and human resources. This support early in the life of an initiative is vital to its success. The level of investment required is directly proportional to the magnitude and complexity of the initiative. The Earth and Planetary initiatives would be expected to have relatively modest needs; the Lunar and Mars initiatives would demand substantial technology development programs, and significant increases in highly skilled personnel and institutional facilities. The need for a dedicated, enthusiastic, and technically competent workforce must not be minimized; the Lunar and Mars initiatives would both require a significant increase in human resources.

The current level of definition of the initiatives, particularly the Lunar and Mars initiatives, is not adequate to reasonably estimate their costs. But while it was not appropriate to attempt to determine the absolute level of resources required by each, it was reasonable to estimate the relative levels through 2010. For each initiative, after the elements not included in current NASA plans were identified, the mass and size of each were estimated in order to determine the transportation requirements for that initiative. There was no attempt, at this early stage, to optimize the transportation system.

Figure 14 compares the resources required by the four initiatives during the next five years. It is important to understand the level of effort needed to support a new initiative during this period, since the country will also be relying on the civilian space program to return the Shuttle to flight, to reinvigorate its transportation system, and to continue serious preparations for the Space Station.

The Lunar, Earth, and Planetary initiatives would take about the same level of investment through 1992. The investment in the Lunar initiative would be primarily in technology and in early transportation development; in the Earth initiative, it would be largely in the development of the polar platforms, data handling system, and transportation; in the Planetary initiative, it would be primarily in technology, and in readying the *Comet Rendezvous Asteroid Flyby* mission for a 1993 launch.

The Mars initiative requires the largest commitment in the early years. This would be primarily an investment in transportation elements and in life science related additions to the Space Station. Transportation and Space Station use have not been optimized, so some reduction might be possible. The message, however, would not change: the country would have to make a major investment in the next five years to land people on Mars in 2005.

The complexity of both the Lunar and Mars initiatives in the year 2000 demands technology developments early in the program. Thus, through 1992 the majority of the Lunar initiative, and a significant portion of the Mars initiative, would be comprised of those technology activities which lay the groundwork for the initiative. Like early work in transportation, there is considerable synergism in the early technology requirements of these two initiatives.

Figure 15 compares the initiatives through 2010. The Lunar and Mars initiatives are nearly an order of magnitude greater in programmatic scope than the Planetary and Earth initiatives. The levels of investment in the Earth and Planetary initiatives peak in the early-to-mid-1990s, and then decrease to levels which remain fairly constant through the first decade of the next century. The Lunar initiative does not require extraordinary resources through 1992, but the commitment builds substantially in the mid-1990s. It peaks in about 2000, at the time of this initiative's first human landing, and stays high through 2010 as the outpost is developed into a permanent base. The total level of effort through 2010 is large, and reflects the ambitious approach to the construction of the lunar base. However, the nature of this initiative allows considerable flexibility. For example, the outpost materials could be delivered to the surface rapidly or at a more deliberate pace; certain capabilities of the outpost could be emphasized and developed before others; or the transition from a temporarily occupied outpost to a large

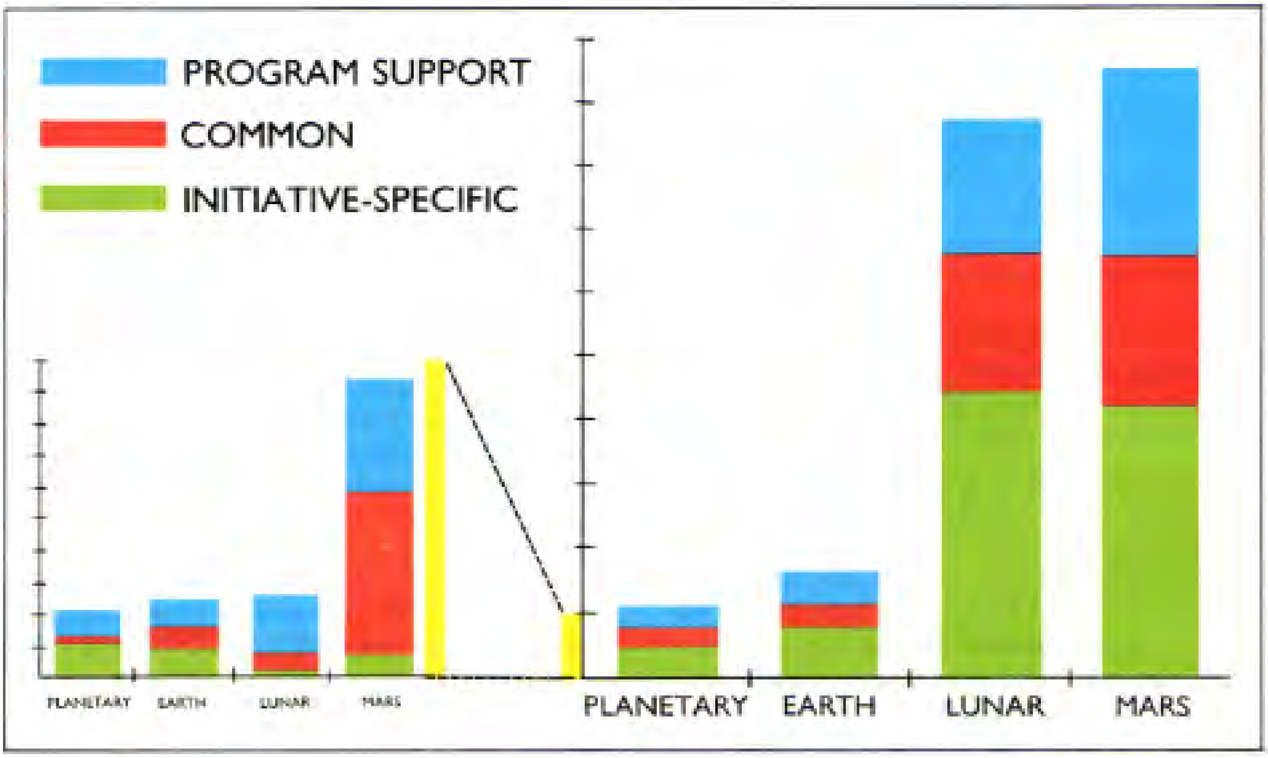

Figure 14.
Resources Required by Initiatives through 1992

Figure 15.
Resources Required by Initiatives through 2010

permanently staffed base could be delayed. Any of these options would significantly reduce the investment through 2010.

Although the Mars initiative offers the greatest amount of human and technological drama, it also demands the greatest investment. The Mars initiative definition included only those elements required for the three sprint missions, the last in 2010, so the level of investment shown is artificially low between 2005 and 2010. The magnitude of the initiative indicates a large commitment of resources, and the timescale dictates that the investment peak in about 2000. It is possible to reduce the early investment to a level comparable to that of the other three initiatives by allowing the first human landing to occur in 2010, rather than in 2005. The 2005 landing was selected at the outset to achieve the major milestone within two decades, but this analysis suggests that this ground rule may not be appropriate for the Mars initiative.

EVALUATION OF INITIATIVES

To this point, we have been considering four specific initiatives, each of which would, if adopted, provide leadership in a particular area of space endeavor. Now it is important to differentiate between an initiative and a strategy. A strategy provides an overall framework and direction; it identifies and prioritizes goals, and defines a course to attain them. An initiative should be an element of a strategy; a part, but only a part, of the larger picture. Initiatives would, of course, be best judged in the context of a strategy.

A process to define and evaluate candidate strategies for the civilian space program is being developed at NASA. This process will seek to identify possible strategies, then assess the likelihood of success and possible implications of each. They will be evaluated in relation to the existing and projected environment, and to the various conditions which may influence their success, such as:

- NASA's strengths, its weaknesses, and its culture
- External threats to U.S. leadership
- Opportunities to exercise leadership
- Optimistic and pessimistic scenarios of uncontrollable factors which influence NASA and its ability to carry out its charter
- The existing U.S. space policy

A successful Mars Rover/Sample Return *mission blasts off, carrying its cargo of Martian samples back to Earth.*

As potential strategies are modified in light of these factors, the result should be a set of two or three distinct, viable strategies whose resource requirements, threats to success, and implications to NASA and the nation are well defined and understood. Although this process is being developed at NASA, it is not NASA's role to determine the overall strategy for the nation's civilian space program; that must be a national decision. NASA should, however, be prepared to present viable options. The potential benefit of this process is evident. It can result in a cohesive strategy that is consistent with national goals, is based on a realistic appraisal of NASA's strengths and weaknesses and the nation's willingness to pursue it, and is resilient to changes in the international environment.

Ideally, of course, a strategy would already be in place. Then each initiative could be judged in light of its compatibility with the overall plan.

While stressing the need for a comprehensive strategy, we can nevertheless conduct a preliminary assessment of the initiatives, recognizing that the important considerations are the quality of the program, NASA's ability to carry it out, and the public's willingness to support it. In the process of this evaluation, we can see the elements of a potential strategy begin to emerge.

Exploration of the Solar System

In the 1960s and 1970s, planetary exploration was a vital and important component of the United States space program. However, while other nations are now vigorously pursuing solar system exploration, the U.S. has launched no planetary missions since 1978.

What does the next decade hold in store? The Soviets have announced their intent to launch three ambitious flights to Mars by 1995, and a Mars sample return mission by 2000. If they are successful with their new-generation spacecraft, and can continue to forge cooperative agreements with European nations, they will clearly have the greater momentum in the exploration of Mars by the mid-1990s.

The Chairman of the NASA Advisory Council's Solar System Exploration Committee has expressed his concern about more than the exploration of Mars: "If we do not continue to carry out these challenging missions to the outer planets and comets and asteroids, we will quickly lose the limited momentum still remaining."

The Solar System Exploration Committee has devised a strategy for planetary exploration through the year 2000, which presented "the minimum-level program that could be carried out in a cost-effective manner, and would yield continuing return of scientific results." NASA should embrace this Core Program.

The *Mars Rover/Sample Return* mission is the centerpiece of the Solar System Exploration Committee's recommended augmentation to its Core Program. This is a mission of bold scientific exploration and high technological drama, and a necessary precursor to the human exploration of Mars. The option for a 1998 launch (two years later than the 1996 date proposed in the initiative) should be preserved.

Although the *Mars Rover/Sample Return* was presented as a U.S. mission in this initiative, it could be performed in cooperation with our allies and/or in coordination with the Soviet Union. In fact, planetary exploration is well suited to international cooperation. The U.S. could benefit significantly by coordinating its *Mars Observer* with the three sophisticated Soviet missions to be launched for Mars over the next seven years. Coordination of these early flights, and exchange of resulting data, would leave the U.S. better prepared to undertake a *Mars Rover/Sample Return* mission, whether in coordination with the Soviets or alone.

Planetary exploration need not be NASA's primary focus, but it offers opportunities to exercise leadership in the international arena through organizing and participating in coalitions to achieve objectives which are consistent with U.S. goals, and it can provide important precursor information for either of the larger human exploration initiatives.

Robotic planetary exploration should be actively supported and nurtured within NASA. Although it does not have the immediate relevance of the Mission to Planet Earth, or the excitement of human exploration, it is fundamental science that challenges our technology, extends our presence, and gives us a glimpse of other worlds. As such, it enjoys widespread public interest and support. Although not necessarily at the pace suggested in this initiative, planetary exploration must be solidly supported through the 1990s.

Mission to Planet Earth

Mission to Planet Earth is not the sort of major program the public normally associates with an agency famous for *Apollo*, *Viking*, and *Voyager*. But this initiative is a great one, not because it offers tremendous excitement and adventure, but because of its fundamental importance to humanity's future on this planet.

This initiative directly addresses the problems that will be facing humanity in the coming decades, and its continuous scientific return will produce results which are of major significance to all the residents of the planet. The benefits are clear to a public that is increasingly concerned about global environmental problems like ozone depletion, buildup of greenhouse gases, and acidification of lakes and forests. And as the environment and its preservation become more pressing issues, the initiative retains its importance for many generations to come.

For this reason it should enjoy sustained public and Congressional support and interest. The U.S. is the only country currently capable of leading a Mission to Planet Earth, but the program is designed around, and requires, international cooperation. Admittedly, the initiative's international scope could complicate its coordination and implementation, but the concept embodied in the initiative enjoys widespread international support. As more and more countries are facing ecological problems, there is increasing interest in a global approach. In fact, this concept is supported by several international organizations, and may emerge as a theme for the International Space Year, 1992. This initiative represents an important opportunity for the United States to exercise leadership in an increasingly significant area.

As the Earth System Sciences Committee suggests, NASA is a natural leader for a Mission to Planet Earth. The National Science Foundation and the National Oceanic and Atmospheric Administration will play important roles, and interagency coordination is crucial. But since the major focus is on observations from space and the coordination and analysis of these (and ground-based) observations, NASA is uniquely suited to lead the effort. It is a natural use for, and extension of, our low-Earth orbital facilities and capabilities, and would not severely drain resources from existing programs. This is an initiative well within NASA's capabilities, and could be carried out with our traditional commitment to excellence.

Should NASA do it? Virtually everyone exposed to this initiative recognized its fundamental importance, and agreed that "whatever we do, we have to do this"; but some felt it may not be bold and visionary enough to stimulate the increased funding necessary. The National Commission on Space conducted numerous public sessions on the space program, and solicited and received comments from a wide cross-section of Americans. The Commission's report lists a series of points "brought forward repeatedly" in those public sessions. One of these was the concern that "any new push into space must supplement living on Earth.... Don't abandon our home planet!"

Plans are already under way within NASA to undertake a subset of this program. The Earth Observing System, which consists of two NASA polar platforms, is being coordinated with the corresponding activities of the European Space Agency and Japan. The first NASA platform is part of the Phase 1 Space Station. The second platform, the instruments, and the payloads remain unapproved. And although the Earth Observing System would represent a major start, it is not sufficient to fulfill all the objectives of this initiative. Critical activities for the immediate future include the coordination of Federal agencies, and the strengthening of international agreements to facilitate the coordination of this international effort.

NASA should embrace Mission to Planet Earth. This initiative is responsive, time-critical, and shows a recognition of our responsibility to our home planet. Do we dare apply our capabilities to explore the mysteries of other worlds, and not also apply those capabilities to explore and understand the mysteries of our own world – mysteries which may have important implications for our future on this planet?

Humans to Mars

Exploring, prospecting, and settling Mars are clearly the ultimate goals of the next several decades of human exploration. But what strategy should be followed to attain those goals?

Any expedition to Mars is a huge undertaking, which requires a commitment of resources which must be sustained over decades. This task group has examined only one possible scenario for a Mars initiative – a scenario designed to land humans on Mars by 2005. This timescale requires an early and significant investment in technology; it also demands a heavy-lift launch vehicle, a larger Shuttle fleet, and a transportation depot at the Space Station near the turn of the century. This would require an immediate commitment of resources and an approximate tripling of NASA's budget during the mid-1990s.

More important, NASA would be hard pressed to carry the weight of this ambitious initiative in the 1990s without severely taxing existing programs. NASA's available resources were strained to the limit flying nine Shuttle flights in one year. It will be difficult to achieve the operations capacity to launch and control 12 to 14 Shuttle flights per year, and assemble, test, and continuously operate a Space Station in the mid-1990s. It would not be wise to embark on an ambitious program whose requirements could overwhelm those of the Shuttle and Space Station during the critical next decade.

This suggests that we should revise the ground rules and consider other approaches to human exploration of Mars. One alternative is to retain the scenario developed here, but to proceed at a more deliberate (but still aggressive) pace, and allow the first human landing to occur in 2010. This spreads the investment over a longer period, and though it also delays the significant milestones and extends the length of commitment, it greatly reduces the urgency for Space

Station evolution and growth, and consequently for transportation capabilities as well.

We must pursue a more deliberate program; this implies that we should avoid a "race to Mars." There is the very real danger that if the U.S. announces a human Mars initiative at this time, it could escalate into another space race. Whether such a race was real or perceived, there would be constant pressure to set a timetable, to accelerate it if possible, and to avoid falling behind. Schedule pressures, as the Rogers Commission noted, can have a very real, adverse effect. The pressure could make it difficult to design and implement a program which would have a strong foundation and adequate momentum to sustain itself beyond the first few piloted missions. This could turn an initiative that envisions the eventual development of a habitable outpost into another one-shot spectacular. Such a dead-end venture does *not* have the support of most NASA personnel. Neither, according to the National Commission on Space, does it have the support of the public. A "theme brought forward repeatedly" in the Commission's extensive public sessions was "a strong wish that our next goal for piloted space activity not be another *Apollo* – a one-shot foray or a political stunt."

THE OFFICE OF EXPLORATION

During the majority of this work, there was no focal point within NASA for studies on human exploration. Recognizing this deficiency, and adopting one of the early recommendations of this study, the NASA Administrator has established the Office of Exploration to fund, direct, and coordinate studies related to human exploration.

Both of the human exploration initiatives described in this work were generated in a workshop or task force environment. The three to four months devoted to their formulation were adequate only to develop the starting point for in-depth studies. The Office of Exploration will be responsible for coordinated mission studies to develop these and other scenarios, to assess mission concepts and schedules, and to study trade-offs in requirements, technology, transportation, and facilities utilization. Advanced technology and transportation requirements cannot be developed in a vacuum. These mission studies will provide a context for planning technology and transportation development and Space Station evolution (and studies in these areas will, of course, feed back into the mission scenarios).

The establishment of the Office of Exploration was an important step. Adequate support of the Office will be equally important, and will be an indication of the commitment to long-term human exploration. There is some concern among observers that the Office was created only to placate critics, not to provide a serious focus for human exploration. Studies relating to human exploration of the Moon or Mars currently command only about .03 percent of NASA's budget (approximately 1 dollar out of 3000); this is not enough.

The scenario described in this report is a rational, sustained program, leading to an outpost and eventual permanent base on Mars. But there is some fear that it is susceptible to transformation into a stunt. This could mortgage the viable space program we hope to have in the 1990s for a "spectacular," which may have few lasting benefits.

Settling Mars should be our eventual goal, but it should not be our next goal. Sending people to and from Mars is not the only issue involved. Understanding the requirements and implications of building and sustaining a permanent base on another world is equally important. We should adopt a strategy of natural progression which leads, step by step, in an orderly, unhurried way, inexorably toward Mars.

Outpost on the Moon

The Lunar initiative is a logical part of a long-range strategy for human exploration. The National Commission on Space recommended that the U.S. follow a "natural progression for future space activities within the solar system," and concluded that the natural progression of human exploration leads next to the Moon.

The establishment of a lunar outpost would be a significant step outward from Earth – a step that combines adventure, science, technology, and perhaps the seeds of enterprise. Exploring and prospecting the Moon, learning to use lunar resources and work within lunar constraints, would provide the experience and expertise necessary for further human exploration of the solar system.

The Lunar initiative is a major undertaking. Like the Mars initiative, it requires a national commitment that spans decades. It, too, demands an early investment in advanced technology, Earth-to-orbit transportation, and a plan for Space Station evolution. Even considering its gradual evolution over the first five years, the ambitious buildup of the lunar outpost envisioned in this scenario would require a high level of effort in the mid-to-late 1990s, and would place substantial demands on transportation and orbital facilities. This is a period when resources may be scarce.

However, this initiative is quite flexible. Its pace can be controlled, and more important, adapted to capability. It is possible to lay the foundation of the outpost in the year 2000, then build it gradually, to ease the burden on transportation and Space Station at the turn of the century.

The Lunar initiative is designed to be evolutionary, not revolutionary. Relying on the Space Station for systems and subsystems, for operations experience, and for technology development and testing, it builds on and gradually extends existing capabilities. Many of the systems needed for reaching outward to Mars could be developed and proven in the course of work in the Earth-Moon region. It is not absolutely necessary to establish this stepping stone, but it certainly makes sense to gain experience, expertise, and confidence nearer Earth first, and then to set out for Mars.

This study did not include an assessment of the level of public support for these initiatives. However, there is considerable sentiment that *Apollo* was a dead-end venture, and we have little left to show for it. Although this task force found some who dismissed this initiative because "we've been to the Moon," it found many more who feel that this generation should continue the work begun by *Apollo*.

Although explorers have reached the Moon, the Moon has not been fully explored. This initiative would push back frontiers, not to achieve a blaze of glory, but to explore, to understand, to learn, and to develop; it would place the Apollo Program into a broader context of continuing exploration, spanning several generations of Americans. And it fits beautifully into a natural progression of human expansion that leads "from the highlands of the Moon to the plains of Mars."

CONCLUSION

Over the last 25 years, as a result of the success of programs like *Apollo*, *Skylab*, *Viking*, *Voyager*, and the Space Shuttle, the American public has come to expect this country to lead the world in space science, space exploration, and space enterprise. But during the 1980s, membership in the once-exclusive club of spacefaring nations has grown, and our leadership is being challenged in many areas.

In today's world, America clearly cannot be the leader in all space endeavors. But we will be the leader in very few unless we move promptly to develop a strategy to regain and retain leadership in those areas we deem important.

Leadership results from both the capabilities a country has acquired and the active demonstration of those capabilities. Thus, the strategy we choose must lay a strong foundation of scientific research and technology development, and must include visible, significant accomplishments that demonstrate the successful pursuit of our stated goals.

To stimulate a discussion of the future of the U.S. civilian space program, four potential leadership initiatives were developed. Each fits comfortably under the umbrella of NASA's charter, each contains visible milestones within the next two decades, and each requires a solid foundation of technology, transportation, and orbital facilities.

It would not be good strategy, good science, or good policy for the U.S. to select a single initiative, then pursue it single-mindedly. The pursuit of a single initiative to the exclusion of all others results in leadership in only a limited range of space endeavor.

A strategy for the U.S. space program must be carefully selected to be consistent with our national aspirations and consistent with NASA's capabilities. It is not NASA's role to determine the strategy for the civilian space program. But it is NASA's role to lead the debate, to propose technically feasible options, and to make thoughtful recommendations.

It is in this spirit that we suggest the outline of one strategy — a strategy of evolution and natural progression. The strategy would begin by increasing our capabilities in transportation and technology – not as goals in themselves, but as the necessary means to achieve our goals in science and exploration. The most critical and immediate needs are related to advanced transportation systems to supplement and complement the Space Shuttle, and advanced technology to enable the bold missions of the next century. Until we can get people and cargo to and from orbit reliably and efficiently, our reach will exceed our grasp; until we begin the technologies proposed by Project Pathfinder, the realization of our aspirations will remain over a decade away.

The strategy emphasizes evolving our capabilities in low-Earth orbit, and using those capabilities to study our own world and explore others. With these capabilities, we would position ourselves to lead in characterizing and understanding planet Earth; we would also position ourselves to continue leading the way in human exploration.

According to the NASA Advisory Council's Task Force on Goals, "Recognized leadership absolutely requires the expansion of human life beyond the Earth, since human exploration is one of the most challenging and compelling displays of our spacefaring abilities."

We should explore the Moon for what it can tell us, and what it can give us – as a scientific laboratory and observing platform, as a research and technology test bed, and as a potential source of important resources. While exploring the Moon, we would learn to live and work on a hostile world beyond Earth. This should be done in an evolutionary manner, and on a time scale that is consistent with our developing capabilities.

The natural progression of human exploration then leads to Mars. There is no doubt that exploring, prospecting, and settling Mars should be the ultimate objectives of human exploration. But America should not rush headlong toward Mars; we should adopt a strategy to continue an orderly expansion outward from Earth.

The National Commission on Space urges 21st Century America "To lead the exploration and development of the space frontier, advancing science, technology, and enterprise, and building institutions and systems that make accessible vast new resources and support human settlements beyond Earth orbit, from the highlands of the Moon to the plains of Mars." The United States space program needs to define a course to make this vision a reality.

EDUCATION

An informed public is essential to both the near-and long-term interests of the nation's civilian space program. The public needs an appropriate base of knowledge of scientific and technological issues in order to make educated decisions on space-related goals. Additionally, today's educational system must produce the high caliber scientists, engineers, technicians, social scientists, and humanists that will actually manage the large-scale space programs that are now envisioned. This means capturing the imaginations and interests of young people at an early stage in their educational careers and encouraging them to pursue studies that will prepare them to actively participate in the space program.

"Unless the youth of this nation are strongly motivated to seek their careers in the often difficult fields of science and technology – of which space is a particularly exciting and rewarding constituent – no amount of federal program emphasis can by itself sustain a long-term leadership role for the U.S. in civil space activities." *U.S. Civil Space Program: An AIAA Assessment*, 1987

"As revealed in a recent national survey of student achievement, an estimated 90 percent of America's high school graduates may not be capable of accomplishing even the most routine high-technology tasks in the future. While up to 90 percent of high school graduates in other countries enjoy a proficiency in math and science, a mere 6 percent of U.S. graduates attain the same aptitudes. . . . This challenge exists at every level from elementary through graduate education." *Pioneering the Space Frontier*, 1986

"Thus, a strong educational system is an essential component of a vital science without which scientific progress would come to a rapid halt. It is most important to ensure that students are being broadly educated in concepts and skills which will be useful throughout their careers." *The Crisis in Space and Earth Science*, 1986

"The future of space biology and medicine will depend on the quality of the young people attracted to the field. NASA should expand its fellowship programs to encourage predoctoral and postdoctoral training at Universities, research institutes, and NASA research centers. Even in a period of reduced flight opportunities, there is exciting important research to be done in ground-based laboratories." *A Strategy for Space Biology and Medical Science*, 1987

ADDITIONAL STUDIES

Several studies provided significant inputs to the work described in this report. Brief synopses of the studies are provided below.

Study: *The Next Giant Leap in Space: An Agenda for International Cooperation*

Sponsor: The United Nations Association of the U.S.A.

Objectives: As part of the UNA-USA's Multilateral Project, to provide an opportunity for private citizens to participate in an examination of the possibilities for international cooperation in the peaceful uses of space; to examine programs and policy options and to develop a list of recommendations for the U.S. to pursue.

Study: *The Crisis in Space and Earth Science*

Sponsor: Space and Earth Science Advisory Committee, NASA Advisory Council

Objectives: To determine the nature of the changes under way in the environment of Space and Earth Science programs; to understand the implications of those changes and to make recommendations to enable NASA to proceed with a long-term, productive program in Space and Earth Sciences; to develop a more rational process for making decisions, especially concerning the selection of major new initiatives; to determine how to optimize the use of limited available resources in such a way as to construct the best possible scientific program.

Study: *NASA Mixed Fleet Study*

Sponsor: Office of Space Flight, NASA Headquarters

Objectives: To formulate an overall NASA mixed fleet launch strategy and policy for the periods 1988-1995 and 1995-2010. The tasks included an assessment of mission needs; a launch vehicle data base; launch vehicle/payload capture analysis; mixed fleet scenario definition; and mixed fleet strategy and policy.

Study: *NASA Life Sciences Working Group*

Sponsor: Administrator's Long Range Planning Office, NASA Headquarters

Objectives: To identify the specific questions which must be answered in the life sciences related to humans in long-duration space flight; to outline the research program required to resolve each issue; to assess NASA's program in terms of the emphasis currently given to each issue.

Study: *National Commission on Space Privatization Issues*

Sponsor: Aerospace Industries Association of America, Inc.

Objectives: To develop criteria to decide where, in the National Commission on Space road map, industry is likely to desire privatization; to identify most attractive candidates in NCOS report for privatization; to suggest NASA actions and ground rules which will increase industry interest in privatization.

Study: *U.S. Civil Space Program: An AIAA Assessment*

Sponsor: American Institute of Aeronautics and Astronautics

Objectives: To conduct an analysis and detailed discussion of both urgent (near-to-mid-term) and selected long-term issues affecting the U.S. civil space program. Four categories of issues were addressed: restoring momentum, maintaining space leadership, organizing and managing the civil space program, and building for the future.

Study: *Task Force on Issues of a Mixed Fleet of Launch Systems*

Sponsor: NASA Advisory Council

Objectives: To examine the issues and questions, and make recommendations to NASA concerning a new policy to conduct the nation's space flight program with a mixed fleet of vehicles. The Task Force addressed three principal issues: an appropriate mix of Shuttle and expendable launch vehicles; appropriate policies and practices for NASA to use in planning and providing launch services; the role NASA should play with respect to current efforts to promote further commercialization of space launch services.

Study: *Assessment of the Soviet Space Program*

Sponsor: Administrator's Long Range Planning Office, NASA Headquarters

Objectives: To undertake a technical review of the capabilities of the Soviet space program to include transportation and launch systems, piloted programs, and space science programs.

Study: *Task Force on Space Program Goals*

Sponsor: NASA Advisory Council

Objectives: To assess the work conducted by NASA to respond to the National Commission on Space report and advise in the formulation of any plans, with the emphasis on nearer-term goals, objectives, program thrusts, and broad policy issues identified by the task force.

Study: *Microgravity Materials Science Assessment Task Force*

Sponsor: Administrator's Long Range Planning Office, NASA Headquarters

Objectives: To determine NASA's role in research, technology development, and hardware development; to identify essential areas of research; to assess NASA's roles in assisting its customers interested in the STS; to develop a plan for using the Shuttle, Spacelab, free-flyers, and Space Station for microgravity processing research.

Study: *A Strategy for Space Biology and Medical Science*

Sponsor: Space Science Board, National Academy of Sciences

Objectives: To develop a strategy for space biology and medical science for the 1980s and 1990s; to identify and describe those areas of fundamental scientific investigation in space biology and medicine that are both exciting and important to pursue; to develop the foundation of knowledge and understanding that will make long-term piloted space habitation and/or exploration feasible.

Study: *Educational Affairs Five-Year Plan*

Sponsor: Educational Affairs Division, NASA Headquarters

Objectives: To develop a five-year plan to improve the quality of science, mathematics, and technology education in the nation's school systems and increase the talent pool of professional and technical personnel needed in the fields of aeronautics and space.

Study: *Committee on Space Technology Needs for the Future*

Sponsor: Aeronautics and Space Engineering Board, National Academy of Sciences

Objectives: To identify enabling and enhancing technology required to support an aggressive civilian space program for the next 30 years, considering both mission goals and the need for reduced costs for acquisition and operations in space; review probable sets of space science, military, space applications, and piloted exploration missions; identify technologies needed to realize and support the defined missions; identify areas where new and innovative approaches are likely to produce exceptional systems, benefits, or new capabilities; define and prioritize a research and technology development program and identify projects and in-space research and technology needs to bring the necessary technology to a state of readiness.

Study: *Space Science in the Twenty-First Century: 1995-2015*

Sponsor: Space Science Board, National Academy of Sciences

Objectives: To identify the major directions for space science for the years 1995-2015. The study was devoted to the review of six major discipline groups: Fundamental Physics and Chemistry, Planetary/Lunar Exploration, Astronomy/Astrophysics, Earth Sciences, Solar/Space Plasmas, and Life Sciences.

Study: *OSTP Comments and Recommendations on the National Commission on Space*

Sponsor: Office of Science and Technology Policy, NASA Headquarters

Objectives: To develop a strategy on how to respond to the recommendations contained in the National Commission on Space report. This is intended to include a review of the current space-related policies and directives, as well as to develop Presidential direction to appropriate agencies to examine the Report and develop potential implementation plans.

Study: *Task Force on International Policy and Program Issues*

Sponsor: NASA Advisory Council

Objectives: To consider the long-range plans of NASA, other nations, and international bodies, with emphasis on opportunities for cooperative activities and alternative forms of such cooperation, as well as areas of present and potential competition; consider the use of international activities as instruments of foreign policy.

Study: *Life Science Strategic Planning Study Committee*

Sponsor: NASA Advisory Council

Objectives: Characterize present NASA life science programs; recommend major NASA life science research goals and objectives; project foreseeable progress in relevant life sciences and technologies; determine what research and development should be supported; formulate technical and scientific strategies to accomplish the selected objectives and goals.

Study: *National Space Transportation and Support Study*

Sponsor: Office of Space Flight, NASA Headquarters; Department of Defense

Objectives: To study the development of a second-generation space transportation system—making use of piloted and automated systems to meet the requirements of all users. A full range of options will be studied, including Shuttle-derived technologies and others. The study will examine the 1995-2010 time frame.

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