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NATIONAL SPACE COUNCIL
EXECUTIVE OFFICE OF THE PRESIDENT
WASHINGTON, D.C. 20500

February 20, 1990

THE CHIEF of STAFF has seen

MEMORANDUM FOR GOVERNOR SUNUNU

FROM: MARK J. ALBRECHT

SUBJECT: Dinner at the Vice President's Residence, February 7, 1990

1. The Vice President has asked me to provide you with a brief summary of the dinner meeting regarding U.S. space policy held at his residence on February 7, 1990. In addition to the Vice President and Mrs. Quayle, Dick Darman and Bill Kristol, there were six prominent space experts in attendance:

   Dr. Bruce Murray, former director of the Jet Propulsion Laboratory

   Dr. Fred Seitz

   Dr. Gerald O'Neil of the Space Studies Institute of Princeton

   LtGen (ret) Bernard Schriever, former head of Air Force Systems Command and first project manager of the US ballistic missile program

   Dr. Lou Lanzerotti, Chairman of the Space Studies Board of the National Research Council

   Dr. Allan Puckett, former CEO of the Hughes Aircraft Corp

2. The Vice President provided a brief overview of the goals and objectives of the President's space program, an assessment of the role of the National Space Council in the formulation and execution of national space policy, and its role in the development of specific implementation strategies and general oversight of space programs. He invited comments from the outside experts.

3. Although each participant provided his own assessment of the efficacy and utility of the National Space Council to this point, there was general agreement with the observation of Bruce Murray, that the formation and early direction of the

Space Council was a significant and positive development in the U.S. space program. As he put it, "A year ago, I was resigned to the conclusion that the U.S. space program was destined for perpetual mediocrity. The Space Council has revived my belief that we can recapture our space leadership."

4. Murray and others hastened to add that, as promising a new start as the Bush administration has made, significant and formidable obstacles remain to be overcome in actualizing a revival of our space program. As he put it, "the glass is half full and half empty. The problem is the federal government is still not really organized to make real progress in space exploration happen." Each expert cited an aging and maladapted NASA bureaucracy as the most significant impediment to progress.

5. A discussion ensued on means for effecting change in the system. Darman observed that significant organizational change in the federal bureaucracy is difficult, time consuming, and risky in terms of actual program outcomes. His view was that all things being equal, it is preferable to accept and isolate certain extant inefficiencies in the system, and to focus on new initiatives as a means for more certain and swift program enhancement. This view was discussed and a general consensus emerged that the best strategy would be to focus on new initiatives, but that these new initiatives should specifically include an emphasis on new management approaches and new organizational arrangements. A specific proposal was made to mandate the formation of a Defense Advanced Research Projects Agency (DARPA)-type organization within NASA with ample resources, serious organizational clout, and a clear charter to seek innovative and creative technical solutions to space challenges.

6. There was a general agreement that "smaller, faster, cheaper" ways of conducting space missions, including Mission to Planet Earth, could be found. There was also considerable criticism of the past development and present state of both the Shuttle and Space Station Freedom, with some disagreement about how radical were the changes that needed to be made. There was considerable agreement that the Europeans and Japanese have been smarter in many aspects of their space program than we have been in the last fifteen years or so.

7. The Vice President initiated a discussion of garnering public support for a rejuvenated space program. Darman observed that the American people believed in exploring frontiers, but also had a strong preference for concrete results. He therefore concluded that a rejuvenated space program must demonstrate early and tangible benefits to the average citizen in order to enjoy significant popular

support. There was general agreement on the need for early benchmarks of progress and success that will be meaningful to the American people, and for the need to explain the space program in terms intelligible to the American people. For example, one could explain how space will contribute to key energy, environmental, or defense needs of the American people in the 21st century.

8. The Vice President specifically challenged the group to identify early, high profile projects that would fit into such an explanation. Dr. O'Neil offered two examples of space mining arguing that early resource development in space would dramatically alter the ability to exploit space energy sources here on earth. Bruce Murray offered several examples including robotic exploration of craters at the lunar poles for the existence of ice, mining of asteroids in near earth orbit, or utilizing the Soviet MIR space station for U.S. caliber medical research as near term efforts with potential high public interest. There was agreement that pursuit and execution of such options in a timely and cost efficient manner would require substantially different management approaches than would likely come from NASA.

9. The Vice President closed the meeting by asking that the participants continue to come forward with near term proposals such as those offered by Murray and O'Neil.

N.B. The Vice President has asked Bruce Murray to assemble a team to meet with him in California during the week of February 25th to add to and deepen the suggestions made at this dinner.

cc: Ed Rodgers

GEORGE C. MARSHALL INSTITUTE

PRESS STATEMENT

Embargoed until
May 1, 1990

Contact: James Frelk
(202)328-5470

A Report on the Lunar and Mars Initiatives: *New Directions in Space*

Summary of Principal Findings by the Marshall Board:

- Major scientific gains in astronomy and the study of the origin and probability of life in the Cosmos can be expected from the lunar base and the exploration of Mars.

- The two missions — and especially the Mars mission — are among the most difficult and challenging technical projects ever attempted.

- Alternatives to the NASA plan for implementing these missions, currently under study in the DOE, claim to hold the promise of major cost reductions and accelerated schedules relative to the NASA plan. *The Marshall Board recommends a solidly funded program for testing and evaluation of these and other promising alternative concepts as a prudent investment.*

- Under the present management structure, control over decisions on technical concepts for manned space flight is vested principally in NASA. At the present time the agency is developing a competing entry, but also will serve as principal judge of the competition. *As a consequence, NASA is both judge and competitor in the competition for selection of the best technical plan for the moon-Mars missions.*

- However, relevant expertise today is widely available in the aerospace industry. It is also available, in many relevant areas, in the laboratories of the DOE and other government facilities and, to some degree, in universities.

- In view of the importance of placing the functions of judge and competitor in separate organizations, the Board recommends that authority for deciding on the technical plan for manned exploration of the moon and Mars should be vested in a national commission external to NASA.

- Members of the Commission will be chosen for outstanding ability in relevant fields of technology and demonstrated competence in the management of very large technical programs. The head of the commission will report directly to the President or the Chairman of the National Space Council.

- The Commission must remain in charge and accept responsibility for the outcome of the program until the technical concepts are established and the complete management structure is agreed upon and in place. Thereafter the commission may dissolve itself, or it may appear to be in the national interest to have the commission continue to act as an advisory and technical assessment during the implementation of the program. *It is critically important that the Commission and staff do not become another permanent element of the bureaucracy rather than a force for innovation.*

ADVANCE COPY
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UNTIL MAY 1, 1990

NEW DIRECTIONS IN SPACE

A Report on the Lunar and Mars Initiatives

George C. Marshall Institute
Washington, D.C.

NEW DIRECTIONS IN SPACE

A Report on the Lunar and Mars Initiatives

Willis Hawkins
Robert Jastrow
William Nierenberg
Frederick Seitz

George C. Marshall Institute
Washington, D.C.

The George C. Marshall Institute provides technical assessments of scientific developments with a major public policy impact.

Authors of *New Directions in Space*

Willis M. Hawkins *is Senior Advisor to the Lockheed Corporation, former Senior Vice President of Lockheed Aircraft Corporation, recipient of the NASA Distinguished Civilian Service Medal, Past Chairman of the NASA Aerospace Safety Advisory Panel, and former Member of the NASA Advisory Council*

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Frederick Seitz *is President Emeritus of Rockefeller University, past President of the National Academy of Sciences and the American Physical Society, former Chairman of the Defense Science Board, former Science Advisor to NATO and recipient of the National Medal of Science.*

The Executive Officer for the study, ***James J. Frelk****, is Executive Director of the George C. Marshall Institute, former analyst for the U.S. House Republican Study Committee, and former Congressional Liaison to the Office of the National Security Advisor.*

CONTENTS

ACKNOWLEDGMENTS

The Marshall Institute is indebted to senior management and technical personnel of NASA and other government and private organizations, who gave generously of their time in briefings and discussions ranging over the technical areas that are expected to play an important role in the proposed lunar and Mars missions. In particular, we would like to thank Drs. Franklin Martin and Mark Craig of NASA Headquarters and Clark Covington of the Johnson Space Center for extensive briefings on the results of the NASA 90-day study, "Human Exploration of the Moon and Mars." We are also indebted to Drs. Lowell Wood and Rod Hyde of the Lawrence Livermore National Laboratory for their report on alternative concepts for the lunar and Mars missions, and to Dr. Steve Howe of the Los Alamos National Laboratory for his presentation of the NERVA and Post-NERVA nuclear propulsion programs.

Richard DalBello and Peter Sharpman of the Office of Technology Assessment gave a very informative account of the problems involved in the reduction of launch operations costs, based on the detailed OTA study of this problem. Professor Marvin Minsky of MIT described the potential of robotics and Artificial Intelligence for reducing the human workload and costs in space operations.

We are indebted to Dr. Jerry Grey, Director of Science and Technology Policy, American Institute of Aeronautics and Astronautics, for an exceptionally lucid and informative account of the Advanced Launch System concept in relation to other vehicle development programs now in progress or under study, and for his

informed and valuable contributions to the discussions in most of the Marshall meetings on the space program. We are also indebted to General Bernard Schriever, former Commander, U.S. Air Force Systems Command, for participating in several meetings and sharing with the Board his enormous fund of knowledge and experience in regard to the management aspects of large technical programs.

Frederick Seitz, *Chairman*
Willis Hawkins
Robert Jastrow
William Nierenberg

PART ONE:
THE NEW EXPLORATION INITIATIVE

INTRODUCTION

This report focuses on one aspect of the current space program: The establishment of a manned base on the moon and the manned exploration of Mars. These missions were announced by the President last year as a major U.S. space policy objective to be implemented under the leadership of the Vice President, acting as Chairman of the National Space Council.

On March 8, 1990, the White House released Presidential guidelines for the execution of the lunar and Mars programs. The guidelines stressed the need for new approaches and the development of innovative technologies with a potential for major cost, schedule and performance improvements. They also called for a competitive environment, with several years allotted to the definition of at least two significantly different human space exploration "reference architectures." Selection of the final technical concepts for the mission is scheduled to occur only after the relative merits of the competing reference architectures have been evaluated.

SCIENTIFIC RETURNS FROM THE LUNAR BASE

The lunar and Mars missions, together dubbed the Space Exploration Initiative, have the potential for rich scientific returns. Astronomy conducted from a lunar base can examine the universe with 100,000 times more resolution of detail than has ever been seen before. An optical interferometer — a network of 42 60-inch telescopes spread across a six-mile area of the moon — will have sufficient resolution of detail to permit the direct detection of planets circling other stars. This network of telescopes will even be able to detect the ozone in the atmospheres of these planets. Ozone would indicate the presence of an abundance of oxygen in a planet's atmosphere.

The earth's atmosphere has an abundance of oxygen only because plants produce it. The presence of oxygen in the atmosphere of another planet would be an almost certain sign of the existence of plant life. On the earth, the appearance of animals followed the appearance of the first plants within two billion years. Since this is a relatively short interval of time when measured against the age of the galaxy and many of its stars and planets, the existence of animal life, in addition to plants, could be inferred as a likely prospect on planets with oxygen-rich atmospheres.

The lunar telescope network could also peer into the hearts of distant quasars — remarkable objects that produce the energy of many billions of suns in a space smaller than our solar system. Astronomers have reason to believe that this extraordinary output of energy is created by a massive black hole at the center of the quasar, whose gravitational force tears apart and consumes the stars circling around it. If this remarkable conjecture is correct, the resolution of detail possible with the lunar telescope network should enable it to observe these stars as they spiral into the black hole and are torn apart by its gravity.

The moon is well suited for the execution of these extremely interesting programs, which would be impossible or prohibitively costly either on the earth or in earth orbit. On the earth's surface, the blurring effects of the earth's turbulent atmosphere makes high-resolution astronomy nearly impossible for all but the brightest sources. If the telescopes were placed in orbit the effects of the earth's atmosphere would be avoided. However, that would mean an array of dozens of separate orbiting telescopes spread across a six-mile area. The individual telescopes in this array would be subject to small but significant variation in gravity across that distance, and would spoil the relative alignment of the telescope mirrors. The mirrors must be aligned, and their distances of separation known, to an accuracy of a fraction of wavelength of light, or a few thousandths of an inch. Station-keeping to preserve the alignment to this precision would be extremely complex and costly. An alternative would be to lace all the telescopes in one rigid, giant-sized platform six miles in diameter. However, constructing such a platform would also be prohibitively expensive.

The surface of the moon, however, provides a stable platform that avoids these difficulties. It also has the advantage of an extremely low level of seismicity compared to the earth. Ground motions produced by lunar seismic events typically are on the order of a few 10-millionths of an inch — 100 times smaller than the maximum relative movement allowable for the telescope mirrors.

RETURNS FROM THE MARS MISSIONS

Valuable scientific returns are also expected from the exploration of Mars. The study of the planet's surface and atmosphere promises to provide the terrestrial geologist and climatologists with information on the basic forces governing the evolution of an earthlike planet and its climate, that could not be obtained solely from the study of the earth.

Another objective of the Mars missions — the search for Martian life, or fossilized remains of life — is of equally great interest to scientists and the general public. *In situ* exploration of Mars and the search for Martian life were initiated by the robotic devices on NASA's Viking spacecraft in the 1970s. The consensus of NASA scientists was that within the limits of the indirect techniques employed by Viking, no evidence for Martian life could be found. However, a variety of other evidence indicates that in the past Mars was considerably warmer and moister, and more congenial to the evolution and continued support of life as we know it, than it is today. Life may have evolved on Mars in this Golden Age. Even if the descendants of that early life did not survive down to the present, their fossilized remains may still exist, on or near the planet's surface.

The discovery of traces of fossilized Martian life would be almost as significant as the discovery that life still exists there today. Either finding — the discovery of life or the fossilized remains of life — would indicate that in the past nature conducted experiments on the creation of life out of nonliving matter on two planets — the earth and Mars — and on both planets the experiments succeeded. It could then be inferred that the chemical evolution of life out of inanimate matter is not a difficult matter for nature to arrange, but something that can happen readily on any planet when conditions are favorable.

A variety of recent evidence strongly suggests that planets are common in the universe, and tens of billions exist in our galaxy alone. The discover of Martian life, or Martian fossils, would imply that life is a common occurrence on these planets, and that, consequently, billions of planets in our galaxy alone are inhabited. This would be perhaps the most portentous scientific finding ever to emerge from the space program.

OTHER FEATURES OF THE NEW SPACE INITIATIVE

While the exploration of the moon and Mars offers much of interest to the scientific community, these missions also have a great deal of interest for the general public. Setting foot on an alien world is a project that appeals to a deeply rooted element in the human psyche — the desire to explore new environments and gather new experiences. At the same time, the two missions — and especially the manned Mars mission — are technically the most challenging and difficult tasks ever attempted in the space program. They could also be both lengthy in fulfillment and very costly. According the initial NASA plan, achievement of the objectives of the lunar and Mars mission will take 25 to 30 years, at a cost reportedly in excess of $500 billion. The call by the White

House for innovative approaches, and the intent to select the best technical plan through a competitive procedure, appear to have been motivated by the lengthy timetable and high price attached to the initial NASA estimates.

INSTITUTIONAL ARRANGEMENTS

The moon and Mars missions will build on the successes achieved by NASA in the lunar landings of the late 1960s and 1970s. The vigor and technical competence of the NASA space program in that period added luster to the image of the United States as a can-do nation. NASA achievements in sending men to the moon and returning them safely are almost universally regarded as a triumph of engineering talent and management skill. The current assignment of responsibilities within the government for the manned missions to the moon and Mars calls for the continuation of the institutional arrangements which enabled NASA to accomplish these earlier tasks with such outstanding success.

The faith of the public and the press in the competence of NASA management was considerably shaken by the Challenger disaster. Fortunately, the post-Challenger period has seen a resurgence of public and Congressional support for the space agency. At the same time, it must be admitted that NASA is a somewhat different institution from the innovative and entrepreneurial agency of the 1960s. In view of the technical challenges and potential cost of the moon and Mars missions, as the nation contemplates the course set by the President in his call for the new Exploration Initiative, it seems worthwhile to examine some of the institutional and management trends in the space program in the two decades since Apollo. This is the task to which the Marshall Board has addressed itself.

BUDGET AND PERSONNEL DEVELOPMENTS

NASA is a considerably smaller agency than it was in the mid-1960s. Over the course of 10 to 12 years, the NASA budget fell by a factor of three, from a peak in 1965 of $27 billion in 1990 dollars to a low of $8.5 billion (1990 dollars) in the 1970s. Budget levels started to rise a few years ago, but are still little more than a third of their peak value in the 1960s.

Drastic reductions in the budgets of federal agencies of this size are unusual. To our knowledge, the last comparable instance occurred nearly a century ago, when Congress cut the budget of the U.S. Geological Survey Agency by a factor of two in one year. It is reasonable to ask how NASA management has distributed these Procrustean cuts, and whether the down-sizing of the agency has preserved the lean and productive character of the earlier NASA.

If NASA were a corporate entity with a bottom line, these questions would be addressed by looking at such performance indicators as profit as a percent of sales. Since the NASA program has no bottom line, other measures of performance must be sought. One pertinent indicator of performance and cost-effectiveness is the number of people working for the agency in relation to the size of its program. As noted, the NASA budget in recent years has been approximately 1/3 of its peak in the Apollo era. However, the space agency has 2/3 as many employees. In other words, the agency employs twice as many individuals per dollar of program money as it did at the peak of its technical effort.

The ratio of number of employees to size of appropriation varies from one agency or program to another, but within a given program, the number of people needed to spend an appropriation effectively would be expected to go up or down roughly in proportion to the size of the appropriation. On this basis, when the NASA budget was cut from roughly $27 billion to $8.5 billion over the course of several years, NASA employment should have declined from its peak of 35,860 to a number in the neighborhood of 12,000. Instead the personnel complement dropped to approximately 22,000. Some economies of scale would be lost in the down-sizing of the agency, but not enough to explain the approximate doubling of the people-to-dollar ratio.

These trends in NASA statistics suggest the development of a certain amount of institutional bloat in the agency as it matured. Personnel statistics reveal other signs of a mature and aging agency. In 1963, as the Apollo program moved into high gear, the average age of NASA employees was 30 — the youngest of any federal agency at the time. In today's NASA, three-quarters of NASA middle and senior level management will be eligible for retirement within five years.

PART TWO: MISSION CONCEPTS

TECHNICAL DEVELOPMENTS

Among the key elements of the initial NASA plan for the moon and Mars missions are: (1) assembly of the interplanetary vehicles in earth orbit at the Space Station; (2) after assembly in orbit, an Apollo-style mission profile with lunar or Mars orbit as an intermediate step prior to descent to the surface; (3) for the Mars mission, an interplanetary flight followed, on arrival at Mars, by; (4) aerobraking for deceleration and the drop into Mars orbit; and (5) descent from moon or Mars orbit to the surface.

Other possibilities exist. A report by the National Commission on Space suggests the attractive concept of a cycling spaceship for the Mars mission, shuttling back and forth between the orbits of the earth and Mars on a transfer ellipse under the pull of gravity alone, without expenditure of fuel. Crews and cargoes rendezvous with the cycler from low-earth orbit or Mars orbit, at the start and finish of each interplanetary flight.

The NASA plan cites nuclear-powered rockets as an alternative technology for the lunar and Mars missions, referring specifically to the advanced technology of gaseous core rockets. The Committee on the Human Exploration of Space of the National Research Council (NRC), in its review of the NASA 90-day study, suggests that this advanced technology for nuclear propulsion, while offering very large potential gains, is too speculative for consideration at the present time.

However, the NRC Committee favors a serious study of current state-of-the-art nuclear propulsion technologies based on the NERVA-class technology, whose feasibility was demonstrated by the Los Alamos National Laboratory (LANL) in the 1960s. The NRC committee report stresses the capability of nuclear rockets for completing the interplanetary transfer between the earth and Mars in one-third to one-half the time required with chemical rockets.

The LANL nuclear propulsion technology would offer important advantages over chemical propulsion in respect to requirements for weight lifted into low earth orbit (LEO), in addition to shortened round-trip travel times to Mars. According to the LANL proposal, a NERVA-type nuclear propulsion technology has the potential for: (i) reduction in weight to LEO from 3.5 million pounds to 1.6 million pounds; (ii) reduction in launch costs from approximately $10 billion to $4 billion; and (iii) reduction in trip time for the Mars mission from 3 years to 1 year, including a 20-day stay on the planet.

The reduction in travel time has the important consequence of diminishing the adverse biomedical impact of lengthy sojourns in space under zero gravity, which is discussed below.

To minimize concern over nuclear safety, the interplanetary nuclear-powered rocket stage would first be boosted by chemical rockets to an altitude of the order of 600 miles, before the nuclear reactor was operated at significant power levels. The NRC committee comments, however, that deployment of nuclear reactors in space will face formidable barriers of public acceptance.

A concept for the lunar mission developed by the Lawrence Livermore National Laboratory (LLNL) omits the intermediate stop in lunar orbit and calls instead for direct descent to the surface after the earth-moon flight, as the basic mission profile. The LLNL concept for the Mars mission resembles the NASA plan except that on arrival at Mars, deceleration and the drop into Mars orbit are to be accomplished by a rocket retroburn as a less risky maneuver than aerobraking.

An alternative approach to the Mars mission, suggested in the report by the National Research Council committee, would first establish advanced bases in Mars orbit and conduct extended reconnaissance from orbit, before the descent to the surface of Mars is attempted. This approach is viewed by the NRC Committee as less risky than the NASA plan.

Need for Artificial Gravity. One of the key questions confronting planners of the Mars manned missions is the potentially destructive biomedical impact of zero or reduced gravity on the crew, during round trips that can last as long as three years. No element of research in preparation for the missions is more important. Enough is already known from Soviet experience with an 11-month stay in orbit, and American experience with Skylab, to indicate that the effects of lengthy stays in zero gravity can be deleterious to health, and possibly fatal.

Experience in Skylab indicates that loss of bone mass could amount to 20 to 30 percent during the two-year round trip to Mars, leaving the weight-bearing bones of the skeleton — especially legs and spine — relatively fragile and liable to fracture on return to earth or in high accelerations. Exercise helps but appears not to eliminate the problem. Calcium dissolved out of the bone also creates a potential in-flight kidney stone problem. Loss of muscle mass, including cardiac muscle, may also be substantial. A Soviet cosmonaut lost 15 percent of leg muscle mass during an 11-month stay in orbit. Knowledge in hand suggests that artificial gravity will be essential for the Mars mission.

Possible collapse of the key elements of the immune system is another potentially serious medical problem that may be created by long stays in zero or deduced gravity.

The report of the National Research Council labels multi-year exposure to weightlessness an "unacceptable risk" for the Mars mission. The NASA plan acknowledges the importance of the problem but does not include artificial gravity in its list of vital technologies for development and apparently does not include it in the initial concept for the Mars flight. The risks inherent in this approach are exacerbated by the proposal for aerobraking on arrival at Mars, which will place a load of several times earth gravity on a crew whose cardiac performance and skeletal structures have been weakened by 10 months of weightlessness en route.

The alternative plan, adopted in the LLNL proposal and based on creation of artificial gravity by rotation of the spacecraft in earth orbit and en route to Mars, holds the promise of eliminating at least one major element of risk in a mission that is certain to involve elements of danger under the best of conditions.

RELATED COST CONSIDERATIONS

The estimated cost of implementing the NASA plan for the moon and Mars mission has been reported to Congress as totaling $541 billion over the next 25 to 30 years. This represents an average annual expenditure of approximately $20 billion, to be added to existing NASA programs currently budgeted at an annual level of roughly $12 billion. The total civilian space budget would be in excess of $30 billion a year over the next 25 to 30 years.

We judge it doubtful that support can be obtained for this program, which will require an annual level of expenditure that is greater than the peak budgets of the Apollo era, continue at that level for up to 30 years, and does not achieve its major goals during the political lifetimes of those who are setting the new course in space and providing its funding.

In our view, the scientific returns and technological benefits from the Moon and Mars missions are of the highest value. But ways must be found to cut costs and accelerate the schedules laid out in the initial NASA plan, so that the program acquires some elements of political realism. We strongly endorse the call by the White House for innovative technologies and unconventional approaches aimed at major cost reductions and a more timely schedule.

The proposal by LLNL for the use of inflatable structures in space is an example of innovative technical concepts that involve major departures from the traditional methods for doing business in space. Inflatable structures for use on the surface of the moon were investigated by the NASA Langley Research Center in the 1960s, but put aside by management although preliminary tests had yielded encouraging results. These structures offered the promise of providing large volumes of habitable working and living space — in earth orbit, en route to Mars, and for bases on the surface of the moon or Mars — at substantially reduced cost.

The inflatable space module tested by Langley achieved a packing ratio or volume compression of 28:1. I.e., the habitable volume in space would be 28 times the volume of the station module as a payload packed for launch. The LLNL inflatables are cylindrical structures 16 feet in diameter, collapsible in one dimension only, accordion-fashion, to achieve a somewhat more conservative packing ratio of approximately 15:1. Cost savings result from the fact that the large reductions in volume permit the launch of an entire earth station as a payload on one heavy lift vehicle. The habitable volume of the station when expanded and outfitted is three times the habitable volume of the Space Station Freedom (SSF). The large volume of the proposed LLNL station allows most gear to be stowed internally, and permits outfitting of the station, and repairs and maintenance, to be conducted internally in a shirt-sleeve environment, obviating astronaut EVAs for station repairs and maintenance. Extensive EVA required for SSF are both costly and dangerous and appear to be a potential drawback to the SSF design.

Cost savings and reduced risk to astronauts from the substantial deduction of EVAs make the LLNL design an interesting concept, and responsive to the White House appeal for innovative, cost-cutting procedures. We judge the proposed LLNL development of inflatable space structures, and the potential cost savings, to be well worth a full test program, including tests in orbit.

PART THREE: AVENUES TO A COMPETITIVE SPACE PROGRAM

THE PRESENT MANAGEMENT STRUCTURE

Thanks to an enlightened research policy in the United States, augmented by a vigorous NASA, commercial and military space programs as well as the commercial aircraft industry, aerospace technology in the U.S. is in very healthy shape. Already in hand are many of the tools needed for maintenance of human existence in space over long periods of time.

Nonetheless, the goal is technically demanding and its realization can turn out to be very costly if conventional approaches are used. Achievement of this formidable capability at acceptable cost and level of risk is a major challenge. It will require not only a solid base of experience with the existing technologies of manned space flight, but also the creativity of the technical mind at its best, applied to the development of innovative procedures for minimizing cost and risk.

NASA has put forward a relatively detailed plan for achieving the goals of a lunar base in the first decade of the next century and the manned exploration of Mars in the second or third. A competing proposal, put forward by the Lawrence Livermore National Laboratory of the Department of Energy, has been mentioned. Other proposals may be forthcoming from the private sector, and from other government organizations as well.

The DOE proposal differs markedly from the NASA plan in concept, cost and schedule. It is likely that the proposals submitted by other organizations will also differ from the NASA plan in greater or lesser degree, since some of the best and most creative technical minds in the American aerospace industry are apt to be attracted to this enormously challenging and exciting task.

Under the management structure for space projects that has been in place up to the present time, NASA develops technical concepts for the manned lunar and Mars missions, and also passes judgment on the merits of alternative concepts. Thus, NASA is preparing an entry in the competition for the selection of the best technical plan for the Moon-Mars missions, but also will serve as the judge of the competition.

This management structure is inherited from an earlier period in the space program, when expertise in the new field of space flight technology was confined to a small group, and a broad technical base in the field had not yet been established. The arrangement which gives NASA monopoly power over decisions on the technical concepts for manned space flight, has not been seriously reexamined since the establishment of the space agency more than 30 years ago. However, the circumstances which made it appropriate to give NASA this power when it was first established have changed markedly in the intervening decades.

Today, the relevant expertise is widely available in the aerospace industry. It is also available to some degree in universities. Many relevant areas of high technology are also very well represented in the laboratories of the DOE and other government facilities.

In view of the changing circumstances which have developed since the creation of NASA, it is essential, in the Board's view, to divorce the functions of competitor and judge in the competition for the best technical approach to the moon and Mars missions, and place these two functions in separate organizations.

Since NASA is certain to play a major role — probably the dominant role — in the implementation of the moon and Mars projects, it cannot reasonably be eliminated as one of the competitors in the competition for design of the final system. This consideration leads us to conclude that the responsibility for judging the competition — the authority for deciding on the technical plan for the manned exploration of the moon and Mars — should be removed from NASA, and vested in a national commission of leaders in aerospace technology and the management of large technical programs.

A NATIONAL TECHNICAL COMMISSION

It is proposed that a national commission be created with members from industry, the universities and the ranks of those who have served the government and understand the complexities of large technical programs. The director of the commission will report directly to the President or the Chairman of the National Space Council but to no lower level of government. The members of the commission will be chosen for outstanding ability in relevant fields of technology, and demonstrated competence in the management of very large technical programs. Establishment of manned bases on the moon and human exploration of Mars at acceptable levels of cost and risk will demand every reserve of technical genius and management skill that can be attracted to the project.

Very few programs in recent technical history can serve as models for the proposed organization. The highly successful Apollo program comes to mind immediately, but it was not a clear example of ordered planning. The achievements of Apollo were more the product of a will to act by an inspired nation, abetted by a large amount of money and talent of some outstanding technical personnel, attracted to a new and challenging program.

Another highly successful model, more pertinent to the present situation because it had stronger elements of permanence and long-term stability, was the Polaris program of the Navy. The Polaris program built on a solid base of existing technology but went far beyond the state of the art at the time, in the development of new and highly creative approaches to technical problems whose solution had never before been attempted. The Polaris project needed new concepts in propulsion, guidance, submarine design and launch systems: The missile was the first entirely solid-fueled ballistic missile developed by the U.S.; it was the first missile to rely completely on inertial guidance; it had the first gimbaled solid-rocket engine designed; and it marked the first attempt ever at an underwater vertical launch.

It was a formidable task to bring these highly advanced technologies individually to fruition. Combining the separate technologies into a smooth working operational system was an even more formidable task. The result of the effort was a product that met requirements and came in very close to the roiginal budget and schedule. These achievements make Polaris one of the best-known success stories in American technical history. How did the Navy do it?

The answer is that Navy management removed the responsibility for major technical decisions regarding Polaris from the organizational units in the Navy that would normally manage the building of the Polaris submarine, and placed this responsibility in a new management entity utilizing substantial talent from outside the government. The new entity, called the Steering Task Group, functioned as a board of directors for the director of the Polaris program. The Polaris Steering Task Group was (and is) an organizational entity very similar to the proposed National Technical Commission on Space. The talented individuals who made up the Steering Task Group understood and respected:

- The technical complexities of a major system
- The pertinent individual technologies required
- The importance of innovation in a pioneering project
- The probable demands on national resources
- The need for agency support within the government

For the membership of the Polaris Steering Task Group, the Navy called on individuals of the highest stature in pertinent fields of technology and technical management. The member chosen for expertise in missile guidance, for example, was Dr. Stuart Draper, head of the MIT Draper Laboratory. The member chosen for expertise in warhead technology was Dr. Edward Teller. Industry members were chosen for very strong technical backgrounds combined with top-level management experience.

Each unit of the Navy involved in support of the Polaris program was represented on the Steering Task Group by its Admiral. However, the Polaris Steering Task Group did not report to any of the organizational elements in the Navy that might have been given responsibility for the entire Polaris program under standard operating procedures. The Chair of the Steering Task Group, who was also the Manager of the Polaris Program, reported directly to the Chief of Naval Operations.

Under direction of the Polaris Steering Task Group, advanced technologies in many different areas were combined in a brilliant, highly innovative and successful program to create the weapons system that most security analysts have regarded for nearly 30 years as the key to American protection from the threat of nuclear attack.

Another example can be taken from the annals of DOD technical management. In the early stages of the ICBM program, the Air Force, faced with a major technical challenge, responded with a similar solution by creating a technical entity outside the government, which later became the Aerospace Corporation. This technical group was responsible critical technical recommendations on ICBM development. Subsequently it underwent a major transformation, but in its earlier form it functioned in a very similar manner to the Polaris Steering Task Group. This management structure resulted again in a highly successful product which created the second major leg of the U.S. strategic nuclear deterrent.

In this instance again, a government agency, faced with a formidable technical challenge, met the challenge successfully by vesting responsibility for major design recommendations in a new management structure, responsible for definition of technical concepts, and *reporting to only the highest levels*. In this way, the government ensured free play for the competitive forces that should be at work in the marketplace of ideas. It ensured that technical innovation would not be smothered by the "not invented here" reflex, the "protect your rear" syndrome, and bureaucratic inertia.

Here are two success stories. What elements do they have in common? What can be learned from them? In each case, a decision at presidential level confronted an agency of the government with a very formidable technical challenge. In each case, the answer was the creation of an autonomous unit responsible for important technical decision, and reporting to the highest levels of government.

ORGANIZATION OF THE COMMISSION

With this preamble, where should the nation start? First, a highly credible Director or Chairman must be chosen who can assume the task without any historic encumbrances. This leader must bring to the task a judgment in technologies and responsible management that has been proven by a long record of successful achievement in large technical programs. The search committee for a suitable director should include individuals of seasoned judgment in technical matters and affairs of government. The search committee must answer to the President or Chairman of the Space Council, but to no one lower in the chain of authority.

After appointment of a Chair, the Commission must be assembled from a group of individuals with expertise in the fields listed below. In addition to the members chosen for individual capabilities, the Commission will provide some members who head organizations that can provide staff support, either informally or formally. Such members of the support staff must be chosen from the rosters of active hands-on agencies. An initial concept of the structure of the Commission is as follows:

- Chair
- System Concepts (Technical); serves as Chair of the Board on Mission Goals (2)

- Propulsion (Technical)
- Long-Term Energy (Technical)
- Life Support (Food-Sustenance-Social)
- Safety (Technical) Chair of the Safety Board (1)
- Structure (Technical)
- Support Systems (Technical)
- Facilities (Technical Planning)
- Finance (Management); serves as Chair of the Board on Program Planning (3)
- Government Support (Management); serves as Chair of the Board on Management Policy (4)
- University Support (Technical-Scientific); serves as Co-Chair of the Board on Mission Goals (2)
- Public Relations
- Legal Counsel

The work of the Commission should be supplemented by a full-time support staff and by part-time boards of specialists, staffed by proven technical leaders. Subjects of the boards of specialists should include:

1. Mission Goals: Exploration, science, human activity concepts, resource development, earth-based data repository — distribution — international participants.
2. Program Planning: Facilities demands, cost patterns, affordability, financing mechanisms.
3. Safety Board: Policy, risk posture and monitoring, concept evaluation, test and simulation for risk assessment.
4. Management Policy: Government-university-industry relationships; development, certification, operations responsibility distribution; leadership selection — role of Commission before and during program activation and during system development and deployment.

COMMISSION TENURE OF OFFICE

The Commission must remain in charge and accept responsibility for the outcome of the program until the technical concepts are established and the complete management structure is agreed upon and in place.

Thereafter, the Commission may dissolve itself; or it may be evident that it would be in the national interest if the Commission were to continue to act as a governing and assessment body during the implementation of the program. It is critically important to ensure that the Commission and its staff do not acquire a permanence that would lead to their becoming another element of the bureaucracy rather than a force for innovation.

STRUCTURE OF THE COMPETITION

Conduct of a timely but thorough competition is the Commission's major task and is the crux of this proposal. It will require that the Commission define how a request for proposals for technical concepts is to be written, and will describe the steps to be taken in the evaluation of proposals. The Board recommends that the competition be conducted to two phases as follows:

Phase I — Broad Concepts

In this phase, the originators of a proposal have maximum freedom with few constraints, except adherence to the basic objective of developing a community of human beings as close to self-sustaining as possible, on the moon and on Mars. The size of the community, time scale, cost, support requirements, booster concepts, etc., are left to the originators of the proposals.

The time allotted to the competition should be six months. Selection of individuals or organizations to receive the requests for proposals (and funding of cost proposals) and is the decision of the Commission.

The product of the preliminary phase is the selection of three "winners" by the Commission, who will be asked by the Commission to prepare detailed final proposals.

Phase II — The Competition

During this phase, the three preliminary "winners" selected in Phase I will be asked to submit a detailed proposal with estimated cost and schedules. Each Phase I "winner" will be instructed to use Commission-directed partners drawn from the roster of competitors in Phase I if promising ideas have been proposed by an organization in Phase I, but the organization making the proposal is judged to be unsuitable for management of the total program.

It is suggested that each of the three entities selected in Phase I should develop a management plan which describes how it would strengthen its proposal by (i) utilizing partners selected by the Commission from the Phase I roster of competitors, and (ii) also incorporating in its planning a subcontractor role for the other two major competitors in Phase II.

The intent of this procedure is that all the technical elements in the country that can make a special contribution shall be incorporated in the program plan. In fact, all three entities chosen for Phase II are to be part of the final program. However, their roles change depending on whether or not they are declared the winner of the Phase II competition.

The three lead competitors should also suggest, as a part of their proposals, how the interface with the federal government would be established.

Time allotted to Phase II should be no longer than one year.

As Phases I and II progress, the Commission should explore alternative possibilities for managing the ultimately defined program, addressing particularly the relationship of the program to existing government agencies. A review of COMSAT history could provide information on the feasibility and likely success of a similar approach to the organization of the interfacing agency between the program and the government. Proposals from competitors in Phase II may contain valuable contributions to the definition of the program-government interface, hence no final decision should be made on this matter until receipt of reports from Phase II competitors.

In addition to its responsibilities for the conduct of the technical competition, the commission will also recommend a management structure, or possibly alternative structures, for implementation of the technical plan.

UTILIZATION OF NASA CAPABILITIES

Establishment of the Commission would recognize that the potential for creative technologies within NASA is no longer as strong as it was in the 1960s. At the same time, it is clear that individual NASA Centers possess a unique capability for implementing various facets of manned space exploration. The NASA Centers are a national asset comparable in importance to the laboratories of the DOE or the AT&T Bell Laboratories and other outstanding research facilities in the private sector. Accordingly, the Commission must be instructed to recommend means whereby the experience and talent of these NASA Centers can be applied, even though they will no longer control concept design and program management for manned exploration.

A critically important step by the Commission, which must be taken at an early stage, is to decide which of the existing government agencies that have a wealth of talent to contribute, can be used on this project without aborting the creative process or overwhelming the program with bureaucratic barriers. A related responsibility will be the careful use of the nation's scientific talent, and particularly the talented university science faculties. This can only be done by tapping the university pool of talent directly for inputs to the Commission. Coordination by or representation through government agencies will blur or smother the contributions of university scientists.

The functions of the NASA operating units — Kennedy Space Center, Wallops, and the Space Control and Tracking portions of Johnson Space Center — should be reviewed with a view to determining whether it would be beneficial to transfer these entities to NASA Headquarters. Some NASA field organizations have not been fully responsive to instructions from NASA Headquarters and, by and large, have not been under Headquarters control. As organizational units attached directly to NASA Headquarters, the operating centers and units are likely to be better coordinated and more economically managed. It is suggested that Headquarters control will avoid the "continuing change" style of management so evident in major space programs, and so costly in time and money.

The Board recommends that consideration also be given to a redefinition of the role and organization status of one of the NASA centers, so that this center assumes the function of an independent government certifying agency for any system in the U.S. space program that involves the presence in space of human beings.

In particular, the function of a government certifying agency would be appropriate for the Marshall Center. Certain areas of the Marshall Center possess areas of technical competence that make them particularly well suited for assumption of certification responsibilities. The certification of space hardware has been relatively informal within NASA, and carried out by the creators of technical designs and hardware for manned space flight. This practice was clearly necessary when only limited numbers of knowledgeable technical experts were available but now that such knowledge is widespread, an independent and entirely objective third-party agency should be created for certification of manned space flight hardware and operations.