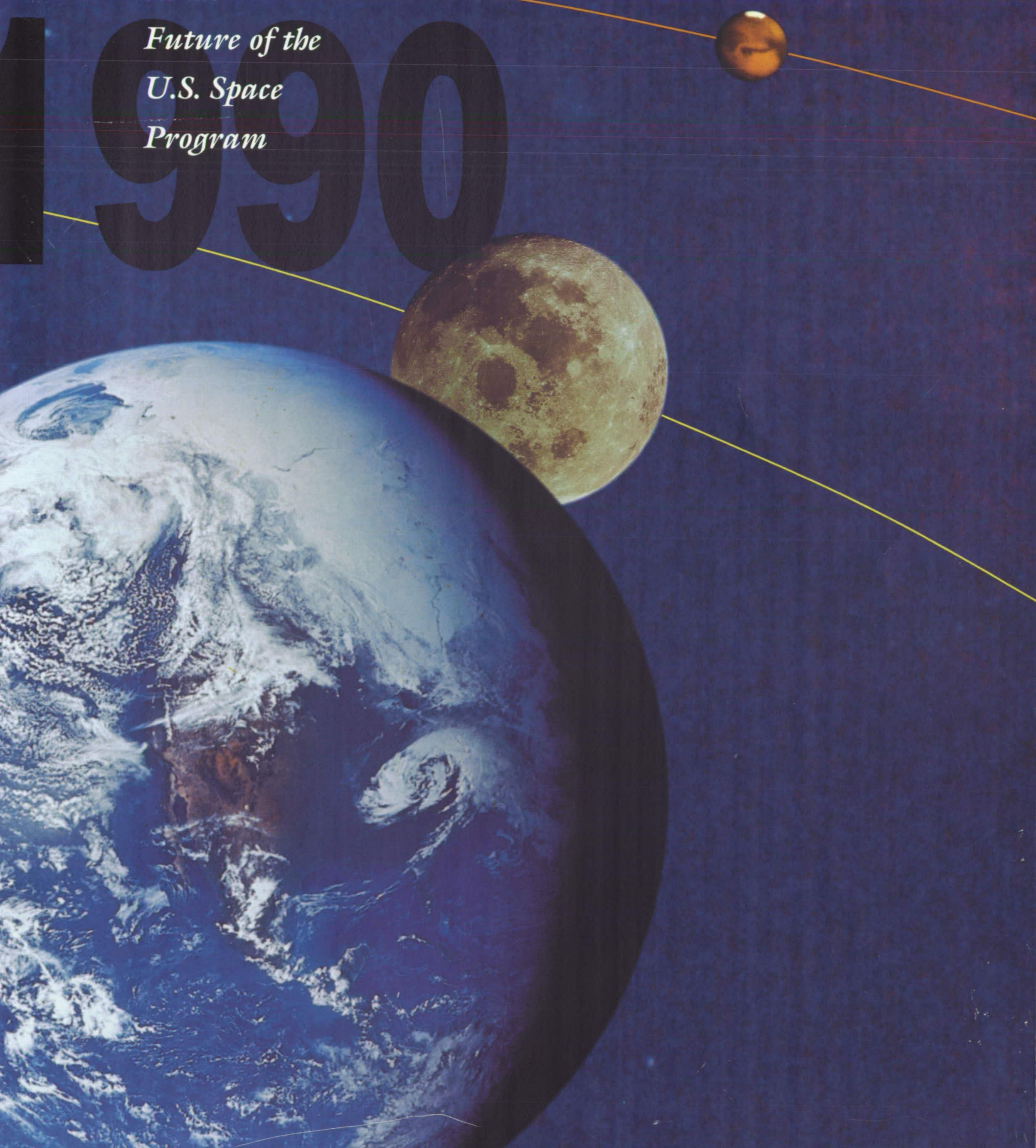
Report of the Advisory Committee on the Future of the U.S. Space Program

1990



Front Cover:
Earth, Moon and Mars will be the principal missions for NASA over the next two decades.

Inside Front Cover:
A reflective scene of Astronaut John W. Young, Apollo 16 commander, as he drives the Lunar Roving Vehicle (LRV) to its final parking place near the end of the third extravehicular activity (EVA-3) on April 23, 1972.

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Report of the Advisory Committee On the Future of the U.S. Space Program

December 1990

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ADVISORY COMMITTEE
ON THE FUTURE OF THE U.S. SPACE PROGRAM
Washington, D. C.

December 17, 1990

TO: The Administrator of NASA

Enclosed, in accordance with the schedule established 120 days ago, is the final report of the Committee on the Future of the U. S. Space Program. The Committee members look forward to reporting our findings with you to the Vice President.

The Committee's twelve members represent a broad diversity of backgrounds, comprising in the aggregate several hundred years experience in space activities but also including one member with no specific prior experience in space matters. The Committee includes individuals with backgrounds in industry, academia, the military, and a former NASA administrator; its perspectives include that of scientists, former astronauts, managers, engineers, private citizens, and former members of Congress. The Committee is unanimous in its findings.

The members are grateful to the more than 300 individuals who appeared before the Committee or its working groups as well as to the several hundred persons who wrote provocative, thoughtful letters -- often filling many pages. The Committee also had the opportunity to read or be briefed on over a dozen earlier studies of specific aspects of the civil space program.

The Committee's hearings were held in public session and were carried over satellite television for those interested. The Committee chose to perform its own inquiry and hence had no research staff but was ably supported by a small but excellent administrative staff. The cooperation and openness of the NASA employees with whom we met was superb, including those involved with our visits to all the NASA centers and headquarters.

We conclude that the civil space program is neither as troubled as some would suggest nor nearly as strong as will be needed, given the magnitude of the challenges the program must undertake in the future.

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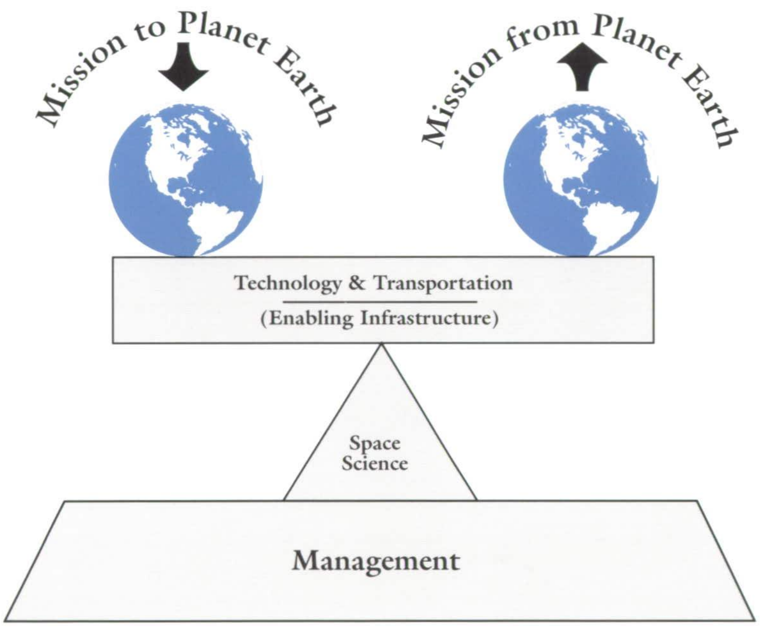


Executive Summary

The United States' civil space program was rather hurriedly formulated some three decades ago on the heels of the successful launch of the Soviet Sputnik. A dozen humans have been placed on the Moon and safely returned to Earth, seven of the other eight planets have been viewed at close range, including the soft landing of two robot spacecraft on Mars, and a variety of significant astronomical and other scientific observations have been accomplished. Closer to Earth, a network of communications satellites has been established, weather and ocean conditions are now monitored and reported as they occur, and the Earth's surface is observed from space to study natural resources and detect sources of pollution.

Problems and Perspectives. In spite of these virtually unparalleled achievements, the civil space program and its principal agent, the National Aeronautics and Space Administration, are today the subject of considerable criticism. The source of this criticism ranges from concern over technical capability to the complexity of major space projects; from the ability to estimate and control costs to the growth of bureaucracy; and from a perceived lack of an overall space plan to an alleged institutional resistance to new ideas and change. The failure of the Challenger, the recent hydrogen leaks on several Space Shuttle orbiters, the spherical aberration problem encountered with the Hubble Space Telescope, and various launch processing errors such as a work platform left in an engine compartment and discovered during launch preparations, have all heightened this dissatisfaction.

Some of the concern is, in the view of the Committee, deserved and occasionally even self-inflicted. For example, the practice of separately reporting the cost of space missions according to accounting categories (which for bookkeeping purposes allocates launch services to a distinct account) results in confusion as to what is the actual cost of a mission.

Yet, in spite of recognized current problems, care must also be taken not to impose potentially disruptive remedies on today's NASA to correct problems that existed in an earlier NASA. The much publicized spherical aberration problem of the Hubble Space Telescope encountered this past year is in fact a consequence of an assembly error left undiscovered in tests conducted a decade ago — in 1980. The decision to launch the Challenger in cold weather, when the seals between rocket motor segments would be most suspect, took place five years ago and has spurred NASA to many management changes. Since the Challenger accident, NASA has increased the emphasis on safety, and has borne the burden of delaying launches when reasonable questions arose over the readiness to launch safely. On the other hand, processing incidents during launch preparation continue to occur in NASA operations, and to be the cause of justifiable concern.

Because of the intense interest in — and scrutiny of — America's commendably open and visible civil space program, it is sometimes easy to overlook the fact that technical problems such as hydrogen leaks, faulty seals and erroneous assembly procedures are not unique to today's space activities, or even to NASA. Although problems of any sort are *most emphatically* not to be condoned, when comparing today's space program with the successes of the past, it must also be recalled that America's first attempt to launch an Earth satellite using the Vanguard rocket ended in failure. By the end of 1959, 37 satellite launches had been attempted: less than one-third attained orbit. Ten of the first eleven launches of unmanned probes to the Moon to obtain precursor data in support of the Apollo mission failed. Three astronauts were lost in a fire aboard the Apollo capsule during ground testing. A cryogenic storage tank exploded during the mission of Apollo 13 en route to the Moon, seriously damaging the spacecraft. During the few months surrounding the Challenger accident, a Delta, an Atlas-Centaur, two Titan 34-D's, a French Ariane-2 and a Soviet Proton were all lost.

Space missions, whether manned or unmanned, are fundamentally difficult and demanding undertakings that depend upon some of the world's most advanced technology. The Saturn V rocket required the integration of some six million components manufactured by thousands of separate contractors. Voyager 2 arrived at Neptune a mere one second behind its final updated schedule after a 12-year, 4.4 billion mile flight, approaching within 3,000 miles of the planet's surface. The information to be gathered by the Earth Observing System could approach 10 trillion bits of information — about one Library of Congress — *per day*. The matter of human frailty is perhaps of even greater import: in the case of the Apollo program, some 400,000 people at some 20,000 locations were involved in its design, test and operation.

Concerns. Nonetheless, given the cost of space activities, in both financial and human terms, and their profound impact on America's prestige throughout the world, no goal short of perfection is acceptable. The Committee finds that there are a number of concerns about the civil space program and NASA which are deserving of attention.

The first of these is the lack of a national consensus as to what should be the goals of the civil space program and how they should in fact be accomplished. It seems that most Americans do support a viable space program for the nation — but no two individuals seem able to agree upon *what* that space program should be. Further, those immediately involved in the program often seem least inclined to compromise for the common good. Some point out that most space missions can be performed with robots for a fraction of the cost of humans, and that, therefore, the manned space program should be curtailed. Others point out that the involvement of humans is the very essence of exploration, and that only humans can fully adapt to the unexpected. Some point to the need for accelerated commercialization of space while others argue the benefits of fundamental science — only to be challenged in turn to prove the tangible value of studies in astronomy.

Second, and closely related to this contentious yet fundamental matter, our Committee believes that NASA is currently over committed in terms of program obligations relative to resources available — in short, it is trying to do too much, and allowing too little margin for the unexpected. As a result, there is the frequent need to revamp major programs, which in turn sometimes results in forcing smaller (scientific) pursuits to pay the bill for problems encountered in larger (frequently manned) missions. Of major importance, in our view, is the fact that margins needed to provide confidence in maintaining cost, schedule, performance, and especially reliability, too often are minimal or absent.

Third, continuing changes in project budgets, sometimes exacerbated by actions needed to extricate projects from technical difficulties, result in management inefficiencies. These demoralize and frustrate the individuals pursuing those projects — as well as those who must pay the bills.

Fourth, there is the matter of institutional aging and the concern that NASA has not been sufficiently responsive to valid criticism and to the need for change.

Fifth, the personnel policies embodied in the civil service system are, in the opinion of the Committee, hopelessly incompatible with the long term maintenance of a leading-edge, aggressive, confident, and able work force of technical specialists and technically trained managers that will be needed by NASA in the years ahead.

Sixth, it is a natural tendency for projects to grow in scope, complexity, and cost. Deliberate steps must be taken to guard against this phenomenon if programs are not to collapse under their own weight — often, as already noted, taking a toll on the smaller projects that must share in the budget.

Seventh, the material foundation of any major space project is its "technological base." It is this base that produces the key building blocks, or "enablers," that make major missions possible — new materials, electronics, engines and the like. The technology base of NASA has now been starved for well over a decade and must be rebuilt if a sound underpinning is to be regained for future space missions.

Eighth, space projects tend to be very unforgiving of any form of neglect or human failing — particularly with respect to engineering discipline. Spacecraft incorporating flaws are not readily "recalled" to the factory for modification. It is this category of problem that has evoked much of the criticism directed at NASA in recent years, although with new technology there are growing opportunities for systems that are "self-healing."

Finally, ninth, the civil space program is overly dependent upon the Space Shuttle for access to space. The Space Shuttle offers significant capabilities to carry out missions where humans are uniquely required — as has been the case on a number of occasions. The Shuttle is also a complex system that has yet to demonstrate an ability to adhere to a fixed schedule. And although it is a subject that meets with reluctance to open discussion, and has therefore too often been relegated to silence, the statistical evidence indicates that we are likely to lose another Space Shuttle in the next several years ... probably before the planned Space Station is completely established on orbit. This would seem to be the weak link of the civil space program — unpleasant to recognize, involving all the uncertainties of statistics, and difficult to resolve.

The Space Shuttle differs in important ways from unmanned vehicles. On the positive side it provides the flexibility and capability attendant to human presence and it permits the recovery of costly launch vehicle hardware which would otherwise be expended. On the negative side, it tends to be complex, with relatively limited margins; it has not realized the promised cost savings; and should it fail catastrophically, it takes with it a substantial portion of the nation's future manned launch capability and, potentially, several human lives.

The Committee recognizes the important role of the Space Shuttle for missions where there is the need for human involvement, and notes that the Space Shuttle is absolutely essential to America's civil space program for the next decade or more. Necessary steps to assure the viability of Space Shuttle operations in this decade should therefore proceed. Nonetheless, the Committee believes, *in hindsight,* that it was, for example, inappropriate in the case of Challenger to risk the lives of seven astronauts and nearly one-fourth of NASA's launch assets to place in orbit a communications satellite.

Agency Responsibilities. Against the backdrop of these and other concerns, the Committee was asked to consider whether some altogether new form of management structure should be established to pursue portions of the nation's civil space program, as has been recommended by various observers. Such a model might include an altogether separate agency patterned after, say, the Strategic Defense Initiative Organization of the Department of Defense, which would be established to pursue major new initiatives such as the Mars exploration program. Another possibility occasionally proposed is to separate the Space Shuttle's operation from NASA so as to permit the space agency to focus upon the pursuit of advanced technology and new leading-edge missions.

The conclusion of the Committee is that changes of such sweeping scope are inappropriate. First, in spite of imperfections, by far the greatest body of space expertise in any single organization in the world resides within NASA. Further, in the case of Space Shuttle operations, the maturity of the system is neither compatible with a (potentially disruptive) shift to a new operator nor, in the opinion of the Committee, is it ever likely to be — even though in principle we favor private sector operations over government operations whenever practicable. NASA and its predecessor, NACA, have followed this practice with regard to the aeronautics program — producing unmatched technology that helped make America's commercial aircraft industry preeminent in the world. A similar effort is needed with respect to space activities — but the Space Shuttle is not, in our opinion, the correct mechanism for accomplishing this objective.

Briefly stated, the Committee believes that NASA, and only NASA, realistically possesses the essential critical mass of knowledge and expertise upon which the nation's civil space program can be sustained — and that the task at hand is therefore for NASA to focus on making the self-improvements that gird this responsibility.

A Space Agenda. The question then arises: "What should be the U.S. space program?" Although it may be tempting to lay out an accelerated plan to accomplish the unaccomplished and to attack the unknown, to do so in the absence of fiscal and technical realism would be a disservice, and would only magnify the problem of management "turbulence" that already has been so costly to the space effort — both in money and morale.

The question thus becomes one of what can and should the U.S. afford for its civil space endeavors in a time of unarguably great demands right here on Earth, ranging from reducing the deficit to curing disease and from improving education to eliminating poverty. The answer to this question is made all the more difficult because the space program touches so many aspects of our lives and contributes to the accomplishment of goals ranging from improving education to enhancing our standard of living and from assuring national security to strengthening communications among the peoples of the world. The space program produces technology that enhances competitiveness; the largest rise and subsequent decline in the nation's output of much needed science and engineering talent in recent decades coincided with, and some say may have been motivated by, the build-up and subsequent phase-down in the civil space program.

Global understanding has been enhanced through the establishment of widespread satellite telecommunications. Countless lives and considerable property have been saved through advanced weather forecasting and the use of spaceborne search and rescue systems. Basic scientific knowledge has been obtained that addresses such important questions as why one planet evolves to become altogether uninhabitable, while another nurtures life.

It can be argued that at least some of these benefits can be reaped by other more direct means. If the objective is to stimulate education, then why not give the money being spent on space to our schools? If the objective is to study the stars, then why not build more and better telescopes here on Earth? To ease poverty, give aid to those in need. Yet perhaps the most important space benefit of all is intangible — the uplifting of spirits and human pride in response to truly great accomplishments —

whether they be the sight of a single human orbiting freely around the Earth at 18,000 miles per hour, or a picture of Uranus' moon Miranda transmitted 1.7 billion miles through space, and taking some 2-1/2 hours merely to arrive at our listening stations even when traveling literally at the speed of light. Such accomplishments have served to unite our nation, hold our attention, and inspire us all, particularly our youth, as few other events have done in the history of our nation or even the world.

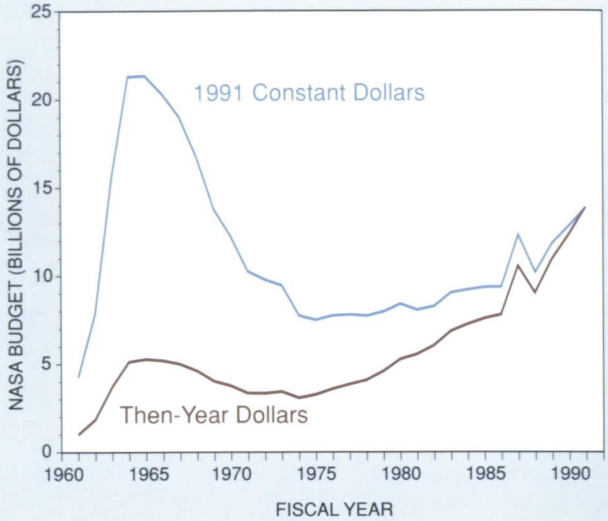
Our Committee concludes that America does want an energetic, affordable and successful space program, a predilection to which we as individuals unabashedly confess. This support has been evidenced in the gradual growth in space funding for nearly two decades (Figure 1). The question remains, however, "What *should* we afford?" In this regard, a historical perspective is helpful. At its peak, during the Apollo years, America spent 0.8 percent of its gross national product on its civil space program (Figure 2). This level amounted to about 4.5 percent of federal spending at the time (Figure 3) and, perhaps more importantly, about 6 percent of the discretionary portion of the federal budget (Figure 4). Today, we as a nation are spending about one-third of the Apollo peak spending as a portion of the GNP — and the fraction of the increasingly pressured total discretionary budget has declined to 2.5 percent.

Presumably reflecting public support, both the Executive Branch and the Congress have recently shown a willingness to increase civil space spending on the order of 10 percent per year (real growth) for a well-executed program. This, therefore, is the baseline selected by this Committee to assure at least a first order fiscal test in our proposals. A larger budget would obviously permit a more energetic space program — while the converse also is true. We recommend an approach which can accommodate, *within limits*, either contingency. Our specific assumption is that the civil space budget will grow by *approximately* 10 percent per year in real dollars throughout most of this decade, leveling out at about 0.4 percent of the GNP. This is a budget that can enable a strong space program — but only if funding is predictable and programs are carefully managed and consistently executed. As a reference, civil space spending recently approved for 1991 represented 8.5 percent real growth over the prior year's spending.

In defining a space agenda we believe it is not sufficient merely to list a collection of projects to be undertaken in space, no matter how meritorious each may be. It is essential to provide a logical basis for the structure of the program, including a sense of priorities.

Figure 1

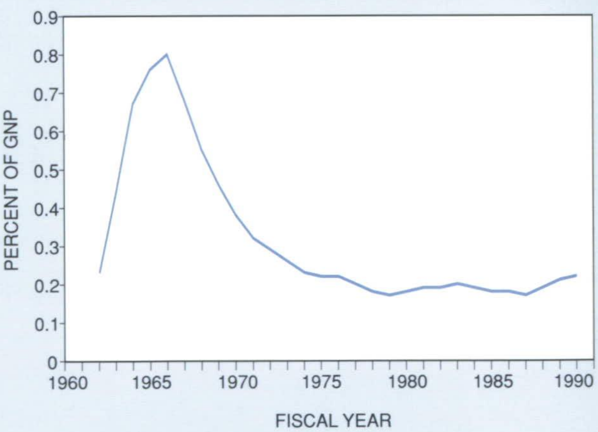
NASA Budget Trend
(Dollars)



Source: NASA

Figure 2

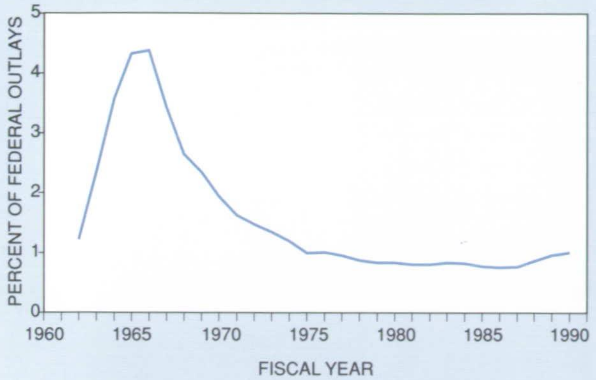
NASA Budget Trend
(Percent of GNP)



Source: Congressional Budget Office - GNP
NASA Budget

Figure 3

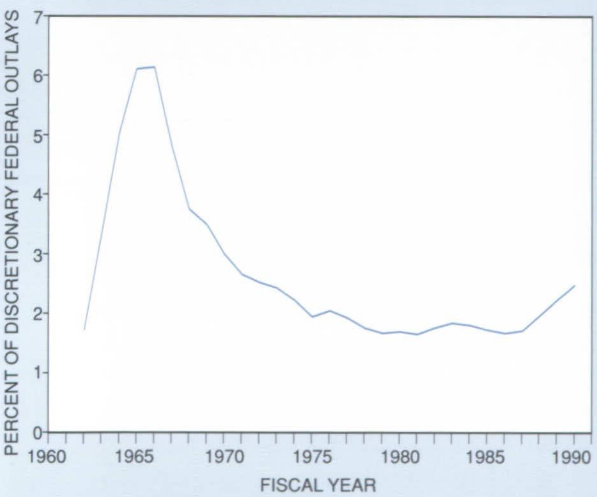
NASA Budget Trend
(Percent of Federal Spending)



Source: NASA

Figure 4

NASA Budget Trend
(Percent of Total Discretionary Federal Spending)



Source: Congressional Budget Office - Total Discretionary Federal Spending NASA Budget

A Balanced Space Program. It is our belief that the space science program warrants highest priority for funding. It, in our judgment, ranks above space stations, aerospace planes, manned missions to the planets, and many other major pursuits which often receive greater visibility. It is this endeavor in science that enables basic discovery and understanding, that uncovers the fundamental knowledge of our own planet to improve the quality of life for all people on Earth, and that stimulates the education of the scientists needed for the future. Science gives vision, imagination, and direction to the space program, and as such should be vigorously protected and permitted to grow, holding at or somewhat above its present fraction of NASA's budget even as the overall space budget grows.

Having thus established the science activity as the fulcrum of the entire civil space effort, we would then recommend the "mission-oriented" portion of the program be designed to support two major undertakings: a Mission *to* Planet Earth and a Mission *from* Planet Earth. Both, we believe, are of considerable importance. The Mission *to* Planet Earth, as we would define it, is the undertaking that in fact brings space down to Earth — addressing critical, everyday problems which affect all the Earth's peoples. While we emphasize the need for a balanced space program, it is the Mission to Planet Earth which connotes some degree of urgency. Mission to Planet Earth, as we would define it, comprises a series of Earth-observing satellites, probes and related instruments, and a complementary data handling system aimed at producing a much clearer understanding of global climate change and the impact of human activities on Earth's biosphere. This effort will provide us with a much better understanding of our environment, how we may be affecting it, and what might be done to restore it.

The Mission *from* Planet Earth is principally, but not exclusively, focused upon the exploration of space. This is where most of the manned space undertakings are to be pursued and as such this tends to be the most costly aspect of the civil space program.

Today, America's manned space program is at a crossroads. The Committee believes that a focus must be given to this program now if it is not merely to drift through the decade ahead. Although there is no particular timetable that can in good conscience be assigned to this pursuit, it nonetheless sorely needs agreement as to direction.

At least in part because of its cost, the manned space program has been at the very hub of controversy swirling around the nation's civil space activity.

It can be argued that much of what humans can perform in space could be conducted at less cost and risk with robotic spacecraft — and in many instances we believe it should be.

But are there not activities in space which properly should be the province of human intelligence, flexibility and being? The Committee found it instructive in this regard to ask whether we would be content with a space program that involved *no* human flight. Our answer is a resounding "no." There *is* a difference between Hillary reaching the top of Everest and merely using a rocket to loft an instrument package to the summit. There *is* a difference between the now largely forgotten Soviet robotic Moon explorer that itself returned lunar samples, and the exploits of astronauts Neil Armstrong, Buzz Aldrin, and Mike Collins. The Committee thus wholeheartedly endorses a far-reaching, but we believe realistic, undertaking in manned space activity, carefully paced to the availability of funds.

But if there is to be a manned space undertaking, what should it be? Surely the goal is not merely to provide routine transportation of cargo to and from space. In this regard, we share the view of the President that the long term magnet for the manned space program is the planet Mars — the human exploration of Mars, to be specific. It needs to be stated straightforwardly that such an undertaking probably must be justified largely on the basis of intangibles — the desire to explore, to learn about one's surroundings, to challenge the unknown and to find what is to be found. Surely such an endeavor must be preceded by further unmanned visits, and by taking certain important steps along the way, including returning for extended periods to the Moon in order to refine our hardware and procedures and to develop the skills and technologies required for long term planetary living.

The Committee offers what we believe to be a potentially significant new approach in the planning of human space exploration. Although we appreciate the arguments for setting a "date certain" for many or even most of our space goals, as did President Kennedy with respect to going to the Moon, we believe that a program with the ultimate, *long term* objective of human exploration of Mars should be tailored to respond to the availability of funding, rather than to adhering to a rigid schedule. This does not demean the importance of the manned space program, but rather is a consequence of the fact that we simply cannot know with any exactness the cost or obstacles which may impede a Mars mission. We do know that, whatever the cost is, it can be spread over many years, and that it will have to endure the changing emphasis of a series of Presidents and Congresses as well as of economic circumstances. We also believe that this is a challenge that could be constructively shared among a number of nations. The challenge, from a management standpoint, is to tailor a program, the first step of which is to generate needed technology building-blocks, which can adapt to the availability of funds. The availability of funding would then determine mission schedule — because the converse is neither economically nor politically practical. Unforeseen fiscal demands would be borne by the program itself rather than off-loaded to other important but smaller (science) programs.

Using this management approach, the Committee believes that a sound, long term human exploration program can be pursued. It provides an important companion to Mission to Planet Earth and clearly states America's intention to stay in space with humans.

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

We do not believe that the Space Station Freedom, as we now know it, can be justified solely on the basis of the (non-biological) science it can perform, much of which can be conducted on Earth or by robotic spacecraft for less cost. Similarly, we doubt that the Space Station will be essential as a transportation mode — certainly not for many years. However, the Space Station is deemed essential as a life sciences laboratory, for there is simply no Earth-bound substitute. The Space Station is a critical next step if the U.S. is to have a manned space program in the future. At the same time, the Space Station can also provide a capability for important microgravity research, and for practical experience in manufacturing under low-gravity conditions. While not, in our opinion, a sufficient justification of Space Station in and of itself, microgravity research does represent an altogether valid element of America's economic competitiveness program.

Given these conclusions, we believe the justifying objectives of the Space Station Freedom should be reduced to two: primarily life sciences, and secondarily microgravity experimentation. In turn, we believe the Space Station Freedom can be simplified, reduced in cost, and constructed on a more evolutionary, modular basis that enables end-to-end testing of most systems prior to launch, and reduces extravehicular flight requirements along the lines NASA is now considering. We also believe that steps must be taken to mitigate dependence on the Space Shuttle.

Given all of this, we would encourage NASA and the Congress not to be bound by the 90-day restructuring period for Space Station Freedom recently directed by Congress. Redesign is simply too important to take less than whatever time may be needed for a thorough reassessment and the establishment of a configuration that can earn stable, long term funding support.

Having thus defined a Mission *to* Planet Earth (MTPE) and a Mission *from* Planet Earth (MFPE) as the keystones we recommend for America's future civil space program, there remain two vital elements of space infrastructure to which attention must be devoted. This infrastructure underpins the nation's ability to actually undertake advanced space missions, and is addressed in two parts: first, the technology base, and second, the Earth-to-space transportation system. Great space pursuits should not be undertaken without proper attention being devoted to these more mundane but critical aspects of the space endeavor.

First and foremost in this foundation-laying effort is the technology base which absolutely must be replenished. America has not initiated development of a new main rocket engine — the muscle of any space pursuit — in nearly two decades. Work on advanced space power systems has been modest; on very high specific impulse propulsion devices even more limited, on advanced concepts such as aerobraking only formative. In fact, the overall technical base underpinning the space program has been permitted to languish in terms of funding for several decades. This effort has not, in recent years, enjoyed the support of the Legislative Branch, or, in earlier years, of the Executive Branch. This must be corrected.

The second element of space infrastructure concerns the provision of high-confidence, reasonable-risk transportation to space. In this regard, the U.S. will be unalterably committed to the Space Shuttle for many years hence. Thus, NASA simply must take those steps needed to enhance the Shuttle's reliability, minimize wear and tear, and enhance launch schedule predictability. Cost reductions also are desirable but secondary to the preceding objectives.

We further conclude that NASA should proceed immediately to phase some of the burden being carried by the Space Shuttle to a new unmanned (but potentially man-rateable) launch vehicle. The new launch vehicle should offer increased payload capacity and be derivable wherever practicable from existing components to save time and cost. Presumably, some of these components could be obtained selectively from the Shuttle system itself, including launch facilities. Future enhancements would use elements derived from the Advanced Launch System technology program in progress under the cooperative management of NASA and the Department of Defense. Such an evolving heavy lift launch system should be designed to produce substantial reductions in launch costs; a major, albeit moderately declining, portion of NASA's budget.

It should be recognized that the substantial near term costs of developing any new heavy lift launch vehicle make a purely financial argument for its existence not particularly compelling. Rather, the objective is to attain a reliable, unmanned vehicle that complements the Space Shuttle and that can be used for routine space trucking, saving the Space Shuttle for those missions requiring human presence. The resulting reduced demand for the Shuttle will help relieve the schedule pressures which have contributed to some of the problems the program has encountered.

Even though selected Space Shuttle components and existing launch facilities might be used for the proposed new launch vehicle, the hazards of coupling failure modes between these two vehicles can be reduced to what we believe is an acceptable level. In short, we must buttress the civil space program's capacity and means of access to space as soon as possible.

Over the longer term, the nation must turn to new and revolutionary technologies to build more capable and significantly less costly means to launch manned and unmanned spacecraft, including those that one day will travel to the Moon and Mars. However, the type of launch vehicle and the specific operational concept that will be needed to propel spacecraft from the Earth's surface to orbit and on to the Moon and Mars will depend on the results of mission architecture studies now underway. In the meantime, while we await the definition of the future spacecraft and launch vehicle requirements, the nation must maintain a vigorous Advanced Launch System technology program. This program, augmented by new propulsion technologies, will provide the elements to enhance our current and evolving launch vehicle fleet and eventually provide the basis for completely new and revolutionary launch systems.

International Pursuits. NASA's accomplishments over the years in space science and technology have helped motivate other nations to pursue space programs of their own. The success and interests of these new participants in the civil space arena places NASA's role in a somewhat changed context as we approach a new millennium, one where our nation must both cooperate and compete. International cooperation can serve to demonstrate leadership, to forge productive relationships and to broaden the range of available opportunities for accomplishment, as has been shown through a long and successful history of NASA-supported international partnerships. But international agreements can also lead to bureaucratic constraints and delays where many levels of approval are required for each decision. The Committee notes that international commitments must be made carefully, supported by all affected parts of the government prior to consummation, including the Congress, and thereafter honored scrupulously. We emphasize that international cooperation should continue to be an integral part of the U.S. civil space program. But we also emphasize that the U.S. should retain management control for critical in-line program elements in certain long term undertakings such as human space exploration, and that the U.S. must continue to have a fully competitive stance in areas such as the access to space itself, i.e., launch vehicles which have broad impact on the fundamental viability of America's civil and commercial space programs.

Some Final Observations. This, then, is the space program that our Committee recommends. A number of further recommendations are offered in the text concerning management improvements, and the all-important matter during the years ahead of attracting to and retaining within NASA a share of the nation's most capable people. Organization charts and improved management practices will prove altogether hollow if NASA is not permitted to attract the extraordinary people needed to successfully pursue the energetic goals prescribed herein.

Many of the recommendations we offer deal with the seemingly mundane aspects of the space program — but, in our view, are of no less importance than the higher-impact recommendations we also offer. These recommendations and suggestions are included in the text and address such matters as enhancing cost estimating capabilities, increasing cost, schedule and performance margins, and strengthening systems engineering.

How shall we pay the bills for all of this? First, as already noted, we assume growth in civil space funding for the next decade. We also recommend a redesign of the Space Station, in part, to reduce cost. We would propose diverting funds from the planned additional Space Shuttle orbiter (but not from support hardware needed to assure the Space Shuttle's continued operational viability) to enable construction of the new unmanned heavy lift launch vehicle. We believe that a new unmanned launch vehicle itself can produce substantial savings — but not in the near term and in the longer term only if we change our processing philosophy and manpower. We recommend configuring the long term manned exploration program, which focuses on Mars but has critical stepping stones along the way in the form of the Space Station and a lunar base, to a schedule that adapts to the availability of funding. And we propose a number of management enhancements that should produce efficiencies and modest attendant cost savings. The most important of this category of improvement, however, is not fully within NASA's wherewithal to implement — namely, the provision of predictable and stable funding. This will require the support of other parts of the Administration and the Congress. The essential role of this support cannot be overemphasized if the U.S. is to have a successful civil space program.

It should also be noted that NASA has a number of other responsibilities to which it must attend. Foremost among these is the continued support of a strong aeronautics program — the linchpin of America's competitiveness in civil aviation. NASA should also continue to help nurture a commercial space industry, as it has in recent years. The Committee is strongly committed to the free enterprise system and believes NASA should do only those things that cannot be satisfactorily performed in the private sector, including academia and industry. There are, of course, many matters which can only be done within the government, including, to name but a few, the pursuit of leading-edge, high cost research with uncertain or long term payoff; planning and providing specialized joint-use facilities; and administering contracts and monitoring the performance of contractors.

Finally, in regard to NASA's other responsibilities, we applaud its on-going efforts to enhance the nation's mathematics and science programs.

We believe that the legacy our generation should leave to the future is that we pioneered the exploration of space, and thereby made important discoveries that will prove of benefit to all mankind. However, space activity is inherently difficult — involving advanced technology and taking place over great distances. It demands reliance upon machines, often very complex machines, which are designed, tested and operated by mortals. It involves rewards which may be intangible.

As we labor under such challenges, we should insist upon excellence. We should strive for perfection. We should demand the utmost of those to whom we entrust our space endeavor. But we should be prepared for the occasional failure. If we as a nation are to place a greater premium on letting nothing go wrong, on not making errors, and on ridiculing those who strive but occasionally fail, than we place upon seeking potentially great accomplishments, then we have no business in space.

The United States in Space

Today's civil space program is the product of its history and its goals for the future. Over time, the basic character of the space program has undergone change, perhaps most notable being the evolution from brief "one-time" events to prolonged operations, including the continuing use of the Space Shuttle, the planned establishment and operation of the Space Station Freedom, and, in the President's words, "... back to the Moon ... this time back to stay." This trend has placed, and will continue to place, increasing demands on NASA as it pursues challenging new development projects — if it does not shed at least some ongoing operational projects. The assignment of responsibility for operation of meteorological satellites to the National Oceanographic and Atmospheric Administration (NOAA) is an excellent example of the needed approach.

A balanced assessment of today's civil space program is facilitated by a review of how we got to where we are, the challenges of space flight, the realities of risk taking and the overall objectives that should be met by any future space program — especially within the realistic constraints of affordability. Each of these topics is addressed in this section.

Historical Perspective

The first American and Soviet space flight projects started only one day apart. On July 29 and 30, 1955, both Washington and Moscow announced plans to launch artificial satellites during the 1957 International Geophysical Year. But the Space Age birth date is clearly October 4, 1957, when the Soviet Union launched its 184-pound Sputnik into orbit, the space equivalent of the Wright Brothers' Kitty Hawk flight just 54 years earlier on December 17, 1903.

What was the perspective of the entire history of aviation by the year 1940, the elapsed time corresponding to our 1990 view of the space program? One significant difference stands out: aviation emerged in a time of relative world peace while space was born amidst tensions brought about by the Cold War. In 1940, the world was poised on the edge of conflict. In 1990, most of the world is united to a degree few of us can recall, despite the adventures of an occasional renegade leader on the world political scene.

The launch of Sputnik shocked our nation, and the reaction was swift and far-reaching (Figure 5). Wernher von Braun's team at Redstone Arsenal was eventually given permission to launch a satellite on the Army's Jupiter C rocket. They succeeded, on January 31, 1958, in the launch of the 10-1/2-pound Explorer I, carrying into orbit two micrometeorite detectors, a Geiger counter, and associated telemetry. Despite its small size relative to Sputnik, these miniaturized instruments gave birth to space science by discovering and mapping what came to be known as the Van Allen radiation belts surrounding Earth.

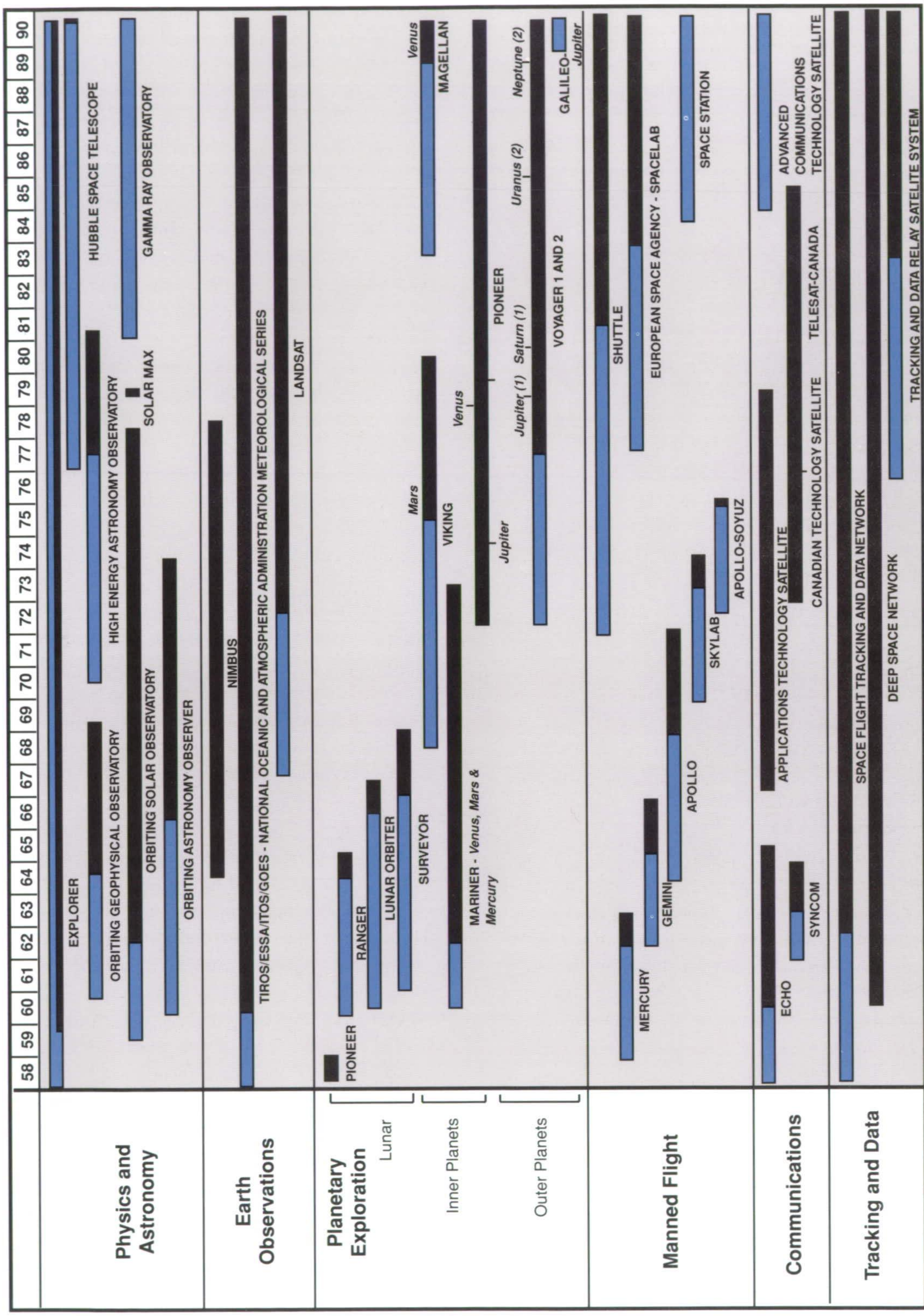
Within a few months, on July 29 Congress passed the National Aeronautics and Space Act of 1958, a far-reaching piece of legislation that created the civilian NASA and provided guidance to our national space program that still appears fresh today. NASA opened for business with a complement of nearly 8,000 employees transferred from the National Advisory Committee for Aeronautics (NACA). By the end of 1960, NASA's personnel rolls nearly doubled with the addition of von Braun's Army Ballistic Missile Agency (later renamed the Marshall Space Flight Center); the new Goddard Space Flight Center, initially staffed from groups at the Naval Research Laboratory and the Naval Ordnance Laboratory; and the Jet Propulsion Laboratory of the California Institute of Technology, then and now a university-operated facility.

But the Soviets were not standing still during those formative years. A month after the launch of Sputnik I, the six-ton Sputnik II rocketed into orbit. Its payload included a 1,121-pound capsule containing the life-support equipment for the canine cosmonaut, Laika, whose presence clearly presaged human space flight. That expectation was fulfilled on April 12, 1961, when the Soviet cosmonaut Yuri Gagarin became the first human to achieve Earth orbit. His dramatic space flight captured the imagination of the world and challenged American technology and leadership. The Kennedy Administration resolved to gain the lead in space. After rejecting an orbiting space station as too easily within Soviet capabilities and an expedition to Mars as too difficult to accomplish in a decade, a landing on the Moon appeared to be an achievable project that would challenge NASA in all areas of space flight, and establish the U.S. as the preeminent spacefaring nation.

Thus, before any American had yet flown in orbit, President Kennedy, on May 25, 1961, asked Congress to direct NASA to land astronauts on the Moon and return them safely to Earth within the decade. The projected $20 billion cost of the first

Figure 5

Civil Space Program: Major Projects



Source: NASA

lunar landing ($94 billion in 1990 dollars) would boost NASA's budget to its peak in 1965, about 0.8 percent of the Gross National Product (GNP), but the alternative of surrendering space leadership appeared unthinkable.

The response was dramatic. The von Braun team initiated a fast-paced project to develop the essential heavy lift launch vehicle, the huge three-stage Saturn V that would lift 120 tons of payload into near-Earth orbit as the first step on the 240,000-mile voyage to the Moon. A giant new launch complex was built at Cape Canaveral; a new manned space flight center was constructed at Houston; a worldwide tracking and data network was established; and new industrial and university research facilities were created across the country. The precursor Mercury and Gemini programs were conducted to develop the necessary technologies for Apollo, and robotic missions were sent to characterize the lunar surface. On July 20, 1969, Neil Armstrong, Buzz Aldrin, and Mike Collins flew the historic Apollo 11 mission that touched down on the lunar Sea of Tranquillity "for all mankind" — on time and within budget.

The Apollo program dominated the public perception of NASA during the decade of the 1960s and beyond, through the launch of Apollo 17 in 1972. But there was also a "silent" civil space program of considerable magnitude underway during this same period, one whose legacy may be even more lasting. During the Apollo period seven successful missions were launched to other planets of our solar system, giving rise to the new field of planetary science. Following the success of Explorer I, more than 70 scientific satellites were launched, each success accruing new discoveries in space physics. Nine successful solar and astronomical observatories were launched, permitting, for the first time, observations of the solar system and beyond from outside our atmosphere.

Science was not the only beneficiary of America's space program. A space applications effort was born on April 1, 1960, when Tiros I, the first meteorology satellite, was launched. Twenty-nine more such satellites were launched during the Apollo period, and the meteorology program became fully operational when the responsibility for operational meteorology satellites was assumed by NOAA and its predecessor agencies in the mid-1960s.

The first passive communications satellite, Echo I, was placed into orbit on August 12, 1960, and the first successful synchronous communications satellite (Syncom II) was orbited on July 26, 1963. A host of other communications payloads gave birth to the communications satellite industry, now generating $2.5 billion annually in the U.S. and $3.7 billion worldwide.

Other satellites were launched to monitor Earth's atmosphere and observe the ocean. The first Earth Resources Technology Satellite (now known as Landsat) was launched in 1972, providing repetitive coverage of the entire Earth (except the Polar regions) every 18 days. James Fletcher, NASA Administrator in 1975, said: "If I had to pick one spacecraft, one space development to save the world, I would pick ERTS (Landsat) and the satellites which I believe will be evolved from it late in this decade."

In retrospect, NASA's accomplishments of the Apollo period provide an historical guidepost for the attributes of the Space Program which America should seek to maintain in the future; one that is capable of providing an impressive stream of scientific information to help us understand the physical order of the universe in ways that can aid this and future generations; and one that insures that the opportunities we open for operating in space can be applied to practical problems here on Earth. A lesson that history offers is that the space program seems to work best, to provide these scientific and practical benefits, when there is an overreaching goal that can generate public support and focus the technological infrastructure on tangible objectives. We believe this to be an important observation.

The Apollo program was an enormous technological achievement, and its momentum carried the NASA manned programs forward into the 1970s. In 1973, Apollo components were modified to launch the 120-ton Skylab prototype space station. The last Saturn rocket launched an Apollo Command Service Module for the 1975 Apollo-Soyuz Project.

But the transient motive behind the Apollo program — and the rapid mobilization of funds and personnel that made success possible — eventually impeded the gradual evolution of a stable and broad public consensus about the nation's purpose in space. Thus, Vice President Agnew, in 1969, appointed a Space Task Group to explore post-Apollo manned space flight alternatives. Proposed programs included a large orbiting space station, a reusable Space Shuttle, continuing lunar exploration, and a mission to Mars. Of these, President Nixon selected to pursue the Space Shuttle. The "Moon race" was won, and national attention turned elsewhere. Saturn V production was terminated, and the space program's budget slumped back to one-third of its 1960s peak in terms of constant dollars.

Nonetheless, impressive space science achievements continued, including the Pioneer 10 Jupiter fly by in 1973, the Mariner 10 Mercury fly by in 1974, the Viking 1 and 2 *in-situ* analyses of Martian materials in 1976, and the Pioneer 11 Saturn fly by in 1979. However, during this period funding for space research and technology dropped more than 80 percent from its peak in 1965. The applications effort also had its unique problems. Despite the successes of meteorology, communications, and Earth observations, government policy increasingly became, in essence: "If there is a user, either private or public, NASA's role should be confined to initial technological demonstration of feasibility. Thereafter, the user should pick up both the cost of, and responsibility for, further development, demonstration and operations." Thus, for example, it was expected that all research and development supporting space communications would be assumed by industry, despite substantial evidence of industry's inability and unwillingness to assume this responsibility. This prompted the ritual lasting several years whereby the Administration would strike all funds for the Advanced Communications Technology Satellite (ACTS), and Congress would reinstate them (Figure 6). Other examples include the transfer of Landsat to NOAA with the stipulation that Earth surveillance activities enter the private domain, despite the fact that the principal customers of Landsat data are government agencies who are loath to commit to any long-term funding for data products, and researchers who generally have government grants insufficient in size to purchase commercial products. Even today the successful meteorological satellite system may suffer unless funding is provided to undertake the development of new instrumentation, either directly to NASA or through inclusion in the NOAA budget and subsequent transfer to NASA.

To continue manned space flight, the reusable Space Shuttle development program was initiated in 1972, the two principal goals being increased access to space and a substantial reduction in the cost of orbital flight. Unfortunately, budget cuts, technical problems and continuing stretch-outs forced design compromises that led to performance shortfalls. The resultant schedule delays and cost overruns also severely impacted NASA's science and exploration programs. NASA's own Advisory Council began preparation of a report with the descriptive title "The Crisis in Space and Earth Science," which outlined the serious difficulties caused by fewer and fewer flight opportunities. The Shuttle is a great technical achievement, but a failure at reducing costs. Nevertheless, these problems were beginning to be forgotten in the early 1980s as 24 Shuttles were successfully flown, and the nation viewed such spectacular achievements as huge satellites being deployed in space and astronauts capturing and repairing malfunctioning satellites and performing in-space experiments. Many took success largely for granted — until January 28, 1986, when the nation was stunned by the Challenger failure.

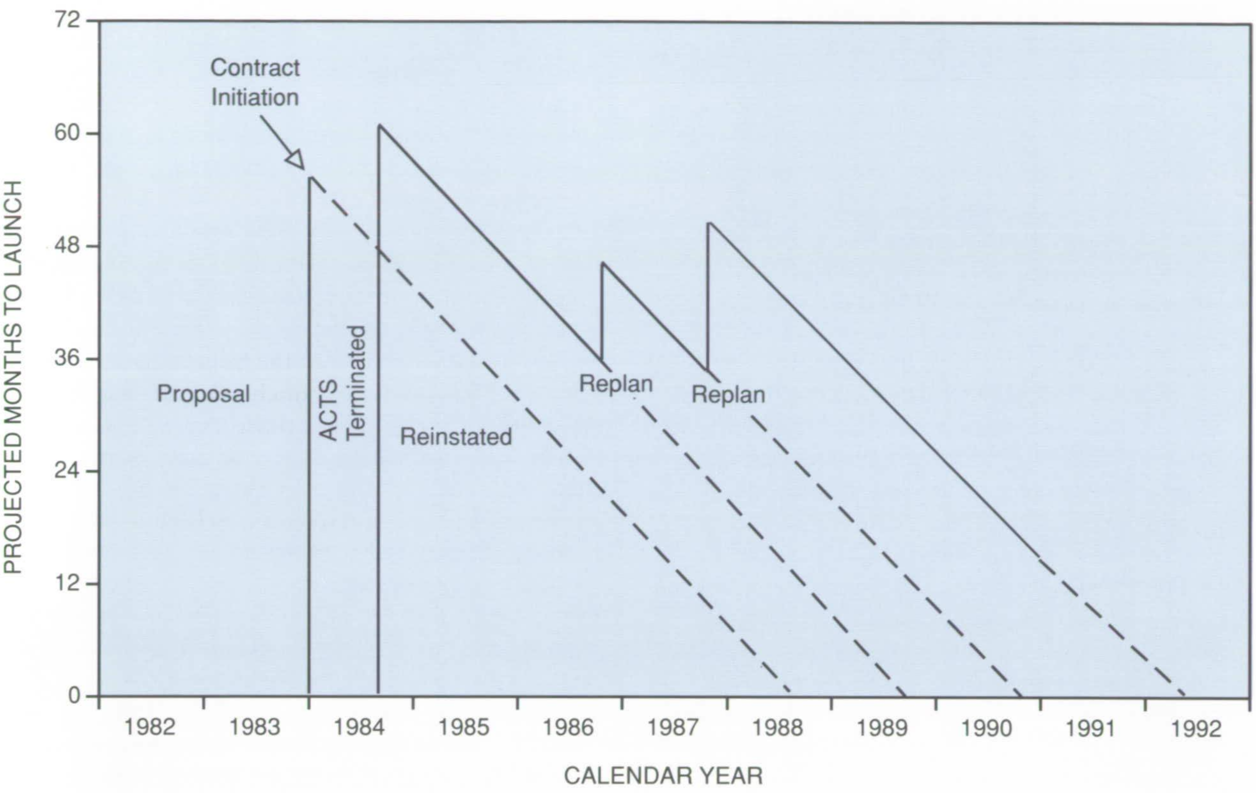
The immediate consequence was that part of the U.S. civil space program that depends on the Space Shuttle was essentially put "on hold" for over 2-1/2 years. An earlier national decision to maximize the economy of the Shuttle by scrapping virtually all expendable launch vehicles, coupled with flight failures among those expendable vehicles that did remain, made it a virtual certainty that nothing could be launched. After decades of success and approbation, NASA felt the wrath of even its friends. The science community found large fractions of their careers "on hold" and the problems outlined by the "Crisis" report were exacerbated. It was a difficult period for the men and women who had built their careers in the space agency.

Even after space flight was re-established in September 1988, considerable disenchantment lingered — encouraged by some parts of the media that by this time had turned "NASA-bashing" into a journalistic art. Criticism for a lack of "goals" was inflicted, even though many parts of the agency had recently improved their strategic planning and established rather specific goals.

Earlier, and to supply needed direction to the manned program, President Reagan initiated, in 1984, the Space Station Freedom program as "the next step in space" that would provide for a "permanent human presence." Its goals were not considered sufficiently specific by the Congress, however, which in turn created the Presidential National Commission on Space to look "beyond the next step" and to recommend long-range goals for the United States civil space program. Unfortunately, the timing of the Commission's report coincided with the Challenger accident, postponing any prospects for implementation.

Figure 6

Advanced Communications Technology Satellite (ACTS)
Launch Readiness Date-vs-Calendar Year



Source: NASA

Thirteen successful Shuttle flights have occurred since operations were resumed in September 1988. Significant Shuttle successes include the launch of the Hubble Space Telescope, the Magellan mission to map Venus, the Galileo mission to Jupiter, and Europe's Ulysses tour around Jupiter and back to the Sun's polar regions. Yet, while there have been significant management changes within NASA and exciting missions are being planned and flown, there remain valid concerns.

Such is the environment as we enter the 1990s.

The Ideal Space Program

The United States has progressed a long way in space since the initial shock of Sputnik. A broad space program has evolved over time, and a space organization structure has emerged which includes governmental, industrial and academic segments. All of these elements were created, modified and adapted to political, economic and international factors which have undergone significant change since the early days of the NASA space program.

We are thus at an appropriate time to step back and view where we are going and what is the best way to get there. Among the most needed ingredients of America's space program is a consensus of support for its goals and its resource needs — whatever they may be. Only with such a commitment on an enduring basis can our nation hope to undertake the challenging, long-term missions that comprise any space program worthy of pursuit. It is instructive to ask the question what an "ideal" space program and organization might look like and what would be its attributes. We would characterize the "ideal" space program as comprising:

- a challenging set of space missions, strongly supported by the American people over extended periods because it contributes to the nation's well-being and is affordable;
- a set of space program building blocks and technology achievements that can be clearly related to the overall mission and affordability levels;
- a program that receives stable, multi-year funding, is relatively insensitive to technology setbacks or even an occasional failure while routinely delivering useful, incremental technological developments, including the occasional "breakthrough;"
- an organization that continually attracts and retains its share of the nation's best talent; and
- an effort that yields visible and significant results, so that the American taxpayer can justifiably believe that the organization is accomplishing its mission efficiently, effectively, and in a fiscally responsible manner while contributing to our pursuit of knowledge, the quality of life here on Earth, and to the inspiration of all peoples.

The President has proposed to the nation a challenging set of space missions but the Congress has not yet appropriated the resources needed to carry them out. There appears to be strong support from the American people for a national space effort, but disagreement on its elements. The United States has a far more capable space organization than is generally appreciated — but one that is not, in our opinion, satisfactorily structured to accomplish its current goals and that, without help, is not likely to be able to acquire and retain the talent needed to carry out these goals over the long-term.

Excellence and Risk Taking

The most fundamental ingredient of a successful space program, aside from the people who participate in it, is the culture or work environment in which it is conducted. There is no more important task for managers at all levels of NASA and its contractors than to nurture a culture of excellence; of complete dedication to product quality and safety; and to total teamwork in achieving that goal. Space is a very unforgiving place. It is highly intolerant of human failings or benign neglect — even of the type that might be considered minor under less stressing circumstances. Space activities demand the utmost of everyone in any way associated with them. In short, there can be no acceptable objective among those who would challenge the vastness of space other than perfection.

Unfortunately, this is an objective not readily met by humans, even though it remains the goal. But perfection can most closely be approached in an organization whose ethos is one of excellence and where this ethos permeates everything it does. Such an organization must insist upon great personal dedication, encourage unwavering self-scrutiny and self-discipline, and promote constructive questioning. It must be clear to all that, in this culture, excellence is more important than schedule and more important than cost — even though these too are important — and that management at all levels can be reliably counted upon to act with this as its set of values.

To sustain such an environment necessitates team-building; the success of the mission is more important than the immediate role of a given individual, center, or contractor. It requires as participants, people who are knowledgeable enough to recognize even the hint of an emerging problem, who are motivated enough to care, and who are courageous enough to do something about it.

For its part, management at all levels must create a culture in which people are actively encouraged to disclose even minor anomalies, to put problems squarely on the table. Equally important, it must be clear that management and workers alike will not for a moment tolerate those who would intentionally undermine this culture of excellence, since to do so is to nourish an organizational cancer.

Such a culture is not easily created. Fortunately, among NASA's strengths over the years has been the focus on mission success, and this focus needs to be continually reinforced. There is no more important responsibility for NASA's management.

But NASA's mission is a difficult one, probably more difficult than that of any other organization in the world. Each Voyager spacecraft has the electronic circuitry of over 2,000 color television sets, yet is required to work for 12 years while traveling from Earth to Neptune. The two Voyager spacecraft schedules were absolutely unforgiving, the planets in their paths aligning themselves only once every 176 years. Yet, by the time Voyager 2 reached Neptune, 4.4 billion miles away and 12 years later, the spacecraft was a mere 22 miles off its charted course and only one second off its updated fly by time. Mechanical challenges are equally impressive. Each Space Shuttle contains some 300 miles of electrical wiring, over 3,000 feet of welds, and over

2.5 million lines of software code. Its pumps propel 65,000 gallons (the capacity of a large swimming pool) through its engines each minute. The power turbine on the Shuttle operates at a temperature of 1,300 degrees Fahrenheit. Just 4 feet away, the pump turbine operates at minus 400 degrees Fahrenheit.

The opportunities for human error are thus formidable. At its peak, Viking involved some 13,000 people, Skylab 32,000, Space Shuttle 52,000, and Apollo 180,000. The Hubble Space Telescope involved a total of over 40 million hours of work. To process a Space Shuttle for flight requires that 1.2 million separate procedures be accomplished.

Furthermore, NASA must do all that it does in the public spotlight — which is, of course, as it should be. But this leads to magnifying any errors. We doubt, however, that any large institution in America, public or private, would present a much better image over the long-term than does NASA, if subjected to similar visibility while pursuing such imposing tasks.

But even with an objective of perfection, such challenging undertakings entail risk. Every person encounters some degree of risk daily. The chances of being killed in an automobile accident are about one in every 100 million miles driven. If we fly to some distant city, the chances are reduced to about one per billion miles.

Risk has been a companion to all great human adventures. Today, astronauts routinely circumnavigate the Earth in 90 minutes. In 1519, Ferdinand Magellan's quest to circumnavigate the globe began with five vessels and a crew of approximately 280. Only one ship and 34 crewmen returned, three years later. Magellan himself did not survive the voyage. In more contemporary circumstances, test pilots in the 1950s had a fatality rate of about one in four as they pushed the barriers of supersonic flight.

In a very real sense, the space program is analogous to the exploration and settlement of the New World. In this view, risk and sacrifice are seen to be constant features of the American experience. There is a national heritage of risk taking handed down from early explorers, immigrants, settlers, and adventurers. It is this element of our national character that is the wellspring of the U.S. space program.

Yet, today there seems to be the danger that the spark of adventure is flickering. As a nation, we are becoming risk averse. We demand only perfection, not as a goal — which we should — but as a reality, though none of us is perfect. We insist on cost benefit analyses although, as Daniel Boorstin, Librarian of Congress Emeritus, has pointed out, "the most wonderful things in life are not cost-effective — like love and children." Success should be sought, and prized when achieved, but not always expected. If it is expected, people will stop taking chances, and if people stop taking chances, nothing great will be accomplished.

NASA has the critical responsibility of doing everything it can to minimize the human risk involved in meeting the nation's space goals, a responsibility that we believe it has now firmly embraced. This requires that NASA's engineers be selected from the best the nation has to offer, that they employ resilient designs, use the best technology available, be meticulous in quality control and impervious to diversionary influences.

Our Committee believes that, as in the past, we as a nation must be prepared to accept the consequences of undertaking endeavors that are worthwhile but present some risk of failure. We should insist on perfection as a very real goal but should not make it more advantageous to avoid failures than to achieve successes. We should not be reckless, nor should we demur from all things entailing the risk of failure. Thus, the Committee believes that the Administration, Congress and the American people must be prepared for the eventuality that NASA will one day — perhaps not too far in the future — suffer another major accident. That is the reality.

As President Kennedy once said: "We do these things not because they are easy, but because they are hard."

General Concerns

Before contemplating recommendations to strengthen America's future space program, it is advisable to have a solid comprehension of the concerns affecting America's present space program, as expressed by knowledgeable observers of, and participants in, that undertaking. Stated otherwise, it is a good idea to understand the problems before proposing solutions.

The civil space program has been subjected to a variety of criticisms, particularly in recent years, some of which in our opinion are justified and others not. Whatever the case, a number of issues have been raised that most observers would agree are deserving of careful attention as the space program moves into what can be a phase of significant future accomplishment. Among these concerns are the following nine issues.

Lack of Consensus

The President has promulgated a set of goals for much of the civil space program together with a schedule for accomplishing them. Questions have been raised, particularly in legislation enacted by the Congress, as to the financial feasibility of achieving these goals — at least in the manner they are currently being pursued. This disparity of objectives and resources is exacerbated by the fact that there exists a wide spectrum of perspectives, even among the participants in the space program, as to what its objectives should be, with some arguing for more emphasis on basic science and others promoting applications, some supporting a centerpiece manned program while others favor far more extensive use of robots. Clearly, any program that involves goals demanding 5, 10 or even 30 years for their achievement must enjoy a solid underpinning of broad, enduring support. The alternative is to suffer through a prolonged sequence of projects that are started, stopped, and restarted, only to be modified again and again.

Overcommitment

It is the Committee's considered judgment that NASA is oversubscribed in terms of the projects it is pursuing, given its financial and personnel resources and the time allotted to pursue them. There are at least two causes for this situation. First, projects have on occasion tended to grow in complexity and size as they have evolved, thereby demanding more resources than originally foreseen. Second, the initial estimates of required resources too often have been understated, particularly with regard to cost. This is an affliction that is by no means unique to NASA, but one that frequently has bedeviled large projects whether pursued in the public or private sector. The challenge of working at the edge of the technological state-of-the-art, which has been almost synonymous with the space program and will probably continue to be, makes all the more difficult the matter of accurately estimating future resource needs.

Whatever the cause, the consequence is clear: too many projects are initiated, resource shortages appear, and margins, if ever any were present in the first place, are inexorably eroded until little or no management latitude remains. The nation's space program of the future must provide at the outset realistic estimates of needed resources and a management approach compatible with the uncertainty therein. Major, high-technology undertakings necessitate the provision of margins — whether they be in goals, schedule, cost, design concept, or all of the above. Any failure to provide adequate margins virtually assures a perpetual resource dilemma for management and continual frustration for workers.

Management Turbulence

"Management turbulence," defined as continual changes in cost, schedule, goals, etc., is closely coupled with the previous two issues. Turbulence is most often the consequence of unforeseen technical problems, lack of design discipline, or unrealistic budget forecasting. Each change induced has a way of cascading through the entire project execution system, producing havoc at every step along the way. A change necessitated at NASA headquarters can affect several centers, each of which passes the change along to a number of major contractors who, in turn, domino the impact onto perhaps hundreds of subcontractors and in turn to even thousands of lower-tier suppliers. At each step, contracts must be renegotiated, people reassigned, designs changed and schedules revised. Soon, a disproportionate amount of time is spent in the pursuit of these change practices instead of producing the end product itself.

The impact of excessive revisions in research contracts conducted by universities has much the same effect. In this case, substantial effort is devoted by academic researchers to the preparation of proposals for research support. When the presumed funds to support the work are subsequently diverted to other objectives, the productive talents of some of the nation's most able people are largely wasted. Perhaps the greatest price extracted by excessive turbulence is, however, the impact it has on motivation and morale of the individuals involved in carrying out projects — both within government and outside — who would prefer to devote their abilities to more constructive endeavors.

Institutional Aging

NASA is now a third of a century old and no longer operates under the relatively more flexible policies, regulations, and legislative environment that characterized its earlier years. Among the concerns that have been most often heard by the Committee has been the suggestion that the civil space program has gradually become afflicted with some of the same ailments that are found in many other large, mature institutions, particularly those institutions which have no direct and immediate competition to stimulate change. It is said that, on occasion, projects appear to have been tailored to help perpetuate the work force, rather than the work force having been tailored to meet the needs of the project. One by-product of any such practice is that it tends to maximize the number of organizations, and therefore interfaces, involved in a task — exactly the opposite of generally accepted management philosophy that argues for minimizing interfaces, the "nooks and crannies" where problems seem to breed. Concern was expressed by the Rogers Commission investigating the Challenger accident regarding the willingness of the various NASA centers to energetically support one another or take direction from headquarters. Similar observations have been expressed not only by individuals outside of NASA, but occasionally from within NASA as well. An intense effort by the current center and headquarters managements has been underway to redress these long-building trends, yet much remains to be accomplished in this most difficult of management challenges, a cultural shift.

Personnel

Contrary to the popular saying, at NASA you do have to be a rocket scientist to fill many of its demanding positions. There are few organizations in the world that confront on a daily basis the challenging, unforgiving tasks that are NASA's everyday fare, whether it be flying a "human satellite," exploring the outer planets with a robot spacecraft, or peeking into the creation of the universe. Achievements such as these demand an adequate share of the nation's best and brightest. To obtain such people NASA must compete head-to-head with a host of other world-class institutions, including the finest of industry and academia who are also seeking these very same people. Unfortunately, broadly applicable civil service practices are not conducive to attracting and keeping people with specialty skills of the type so much in demand at NASA (and elsewhere). In the past, the challenge and excitement of the space program has been a significant inducement for exactly the type of people one wishes to attract. However, this form of currency has in recent years been somewhat devalued as criticism has been heaped upon the civil space program and its participants, and as the image of public service in general has been permitted to deteriorate — a development that the Committee decries.

NASA today is moderately competitive in acquiring new college graduates, but not competitive for experienced engineers and senior, technically-qualified managers. Deterrents include non-competitive pay, lack of sufficient coupling of pay and performance, inadequate compensation for moves, excessively bureaucratic hiring and firing procedures, and limited career development practices. In addition, NASA has now largely lost a principal source of leavening and fresh perspectives that was available throughout its early years in the form of mid-level employees who would forego positions in academia or industry to serve several years in government. This latter source of experienced personnel has largely been denied in the effort to avoid potential conflict-of-interest situations. In short, given current policies, the Committee is not sanguine that in the future NASA will be able to obtain or retain the necessary cadre of skilled personnel in a field where the most critical asset is the talent of the individual participants.

Technology Base

Next to talented people and a culture of excellence, the most important underpinning of the civil space program is its technology base. This base comprises the effort to develop key building blocks such as engines, computers, materials, and the like that enable significant new missions to be successfully undertaken. Unfortunately, this building-block effort does not always compete favorably with the missions themselves in contending for funds and skilled personnel. Often, fundamental development programs are less glamorous, less visible, have no organized constituency, and generally are comprised of a number of small- and medium-size projects.

Nonetheless, the consequences of neglecting the technology base are very measurable indeed, not only impacting America's competitiveness but inducing major projects to be undertaken without a sufficient technological foundation in place. When problems are subsequently encountered, these projects must be restructured, usually accompanied by an increase in cost. The result is that major pursuits, with large work forces that cannot afford to be held in abeyance, siphon money from smaller research projects or from the technology base itself, and the whole cycle starts anew. It seems clear that our technology base, including its supporting facilities, must be revitalized and afforded priority commensurate with its importance if major new projects are to be pursued on a realistic basis in the decades ahead.

Big Projects vs. Little Projects

A debate continues over the efficacy of pursuing a few large space projects as opposed to (many) small projects. It has been asserted, sometimes justifiably, that cost overruns in large projects often have been to the direct detriment of small research and technology undertakings, which are called upon to pay the bills. This concern far transcends the civil space program and is endemic to the "Big Science – Little Science" debate in general.

Some large projects are clearly unavoidable if one wishes to pursue certain goals. One cannot, for example, send humans to the Moon in other than a very big project. Large projects also sometimes offer economies of scale, permitting the sharing of a computer, attitude control system, communications link, or tracking channel among a number of component experiments. Nonetheless, a great deal of useful science can be undertaken for the cost of a single major project. Furthermore, the time scale of large projects often is incompatible with the needs of academic institutions seeking to educate the nation's future scientists and engineers, and seeking research projects in which to participate. Clearly, no single answer to the "big vs. little" dilemma exists, but it must be recognized that bigness is not of itself goodness; that the natural tendency of most engineering pursuits seems to be toward bigness; that specific guards must be established against unjustified growth; and that, in any event, the issue must be addressed on a case-by-case basis.

Attention to Detail

Although not specifically within the purview of this Committee, the technical problems that have occurred in the past in the civil space program have a bearing on the formulation and execution of any future space program. Further, these problems have been at the root of much of the recent criticism directed at NASA. Such occurrences cannot be assigned a single cause, nor can they be precluded by promulgating still more regulations. Their prevention requires redundant, flexible designs, explicit test procedures, independent checks and balances, unwavering discipline and, above all, inquisitive, penetrating, and challenging people — people who are not satisfied merely to fill the squares of regulations but rather are continually questioning and ferreting out anomalies to be placed in full view of all involved.

Resilience of the Space Transportation System

America's civil space program is heavily dependent upon the continued successful and timely operation of the Space Shuttle. The Space Station Freedom, for example, demands a substantial number of Shuttle launches on a relatively predictable schedule. The Shuttle, even with its 1970's technology, is demonstrably capable of performing such undertakings as man-tended satellite repair and recovery missions. However, it has not realized the economic benefits formed from the foundation of its original justification, and in terms of operating rhythm it in no way emulates the functioning of commercial airlines with which it is sometimes (inadvisably) compared. It is the Committee's belief that routine, on-time operation is not likely in the foreseeable future. It is concluded, therefore, that we are today overreliant on the Space Shuttle as the backbone of the civil space program.

The Findings

Each of the major issues addressed by the Committee is examined in this section of the report and, where appropriate, recommendations are offered.

Goals and Affordability

Goals. The National Aeronautics and Space Act of 1958, as amended, has served this country well and served to establish the fundamentals of America's space program. Much of the mission statement contained therein, despite its origin over 30 years ago, is equally valid today, including:

- "...it is the policy of the United States that activities in space should be devoted to peaceful purposes for the benefit of mankind."
- "...NASA [should] seek and encourage to the maximum extent possible the fullest commercial use of space."
- "...[the program should seek] expansion of human knowledge of the Earth and of phenomena in the atmosphere and space."
- "...[an objective is] the preservation of the role of the United States as a leader in aeronautical and space science and technology..."
- "...[there should be] cooperation by the United States with other nations and groups of nations in work done pursuant to this Act..."

The Space Act clearly sets forth the basic rationale for today's space program. In fact, however, our original national space effort was to a considerable extent founded on the need to assure national security. The revelation of the advanced state of Soviet technology, reflected in Sputnik, and the development of intercontinental ballistic missiles propelled America's space and advanced military technology efforts for many years. Fortunately, the current world situation is in stark contrast to that which existed in the late 1950s and 1960s. This change is punctuated by events in the Soviet Union and Eastern Europe, arms control initiatives, and improving international relations in many (but not all) parts of the world.

However, other concerns are replacing the primary military threat to our national well being. These new threats are economic and ecological, and are closely tied to other important issues such as education and energy. From an economic viewpoint, many nations around the world threaten U.S. technological leadership and competitiveness. Deputy Secretary of Commerce Thomas J. Murrin, in testimony before the Committee, summarized the situation, stating: "While space missions may uplift our spirits and enhance our prestige, it is economic competition which will ultimately determine our standard of living, the jobs that we and our children hold and, to a large extent, our national security and our international influence. The potential for space activities to enhance our economic progress will directly affect this nation's ability — and its will — to continue to be a permanent leader in the world." In these changing times, our space program clearly must be increasingly responsive to our future economic needs.

Another emerging threat that will impact our quality of life arises as a result of abuse of our natural environment. To implement effective and economical solutions to environmental problems, we must first understand them. Observations from space of our changing ecosphere will very likely prove invaluable in this endeavor.

The basic "imperatives" of today's national civil space effort are, therefore, to:

- sustain our heritage to learn, explore, and discover;
- maintain our technological *competitiveness* in global markets; and
- enhance the *quality of life* for all people on Earth.

In addition, the civil space program should continue to contribute to the national security and foreign policy objectives of the United States.

Affordability. The affordability of these space goals is a major concern, particularly in the current fiscal environment. Furthermore, we must recognize that it is difficult, if not impossible, to determine the precise cost of certain long-term future space endeavors — particularly the more costly ones. Uncertainties of yet-to-be-demonstrated technologies alone preclude precision in estimating costs. Nevertheless, long-range programs such as those characteristic of space efforts demand that we be prepared to undertake long-range funding commitments. This has in fact been the case in the past where substantial sums were devoted over reasonably long periods to civil space projects — as indicated in the following table:

Program	Program Development Cost (Billions of 1990 Dollars)	Total Program Cost as Percent of 1967 GNP*
Apollo	$94.07	2.38
Shuttle	27.77	0.61
Skylab	9.23	0.22
Viking	2.94	0.07
Hubble Space Telescope	2.08	0.04
Galileo	1.27	0.03

*Constant dollars in peak funding year

During the peak funding years of Apollo in the mid-1960s (well before the lunar landings), an emerging basis for space program affordability was being established, at least for that time, consisting of approximately 0.8 percent of the Gross National Product, 4.5 percent of the federal budget and about 6 percent of total federal discretionary spending.

Since the sixth and last Apollo landing on the Moon, the NASA budget has declined by each of the above measures. For the past 15 years, it has hovered in the vicinity of 0.2 percent of the GNP, 1.0 percent of the federal budget, and 2.5 percent of total federal discretionary spending.

A number of studies have outlined vigorous space programs, many quite similar to the President's recent initiative. While these programs differ somewhat in content and schedule, they are surprisingly consistent regarding the near-term level of funding required. Based on our own review, we believe that a reinvigorated space program will require real growth in the NASA budget of approximately 10 percent per year (through the year 2000) reaching a peak spending level of about $30 billion per year (in constant 1990 dollars) by about the year 2000. Such a program will:

- provide for the basic infrastructure to operate NASA, the recommended Science program, the recommended and expanded Technology program, a Mission to Planet Earth, a new start on a phased and evolutionary heavy lift launch vehicle and a reconfigured Space Station; and
- provide sufficient funds to begin laying the foundation for lunar and Mars missions on a schedule that will permit real progress and significant periodic technical achievements leading to a manned Mars mission in approximately 30 years, i.e., Mission from Planet Earth.

If a level of funding of about 0.4 percent of the GNP can be achieved by 2000, and sustained thereafter, then a vigorous but controlled civil space program can be pursued. The Committee believes that, given the benefits it provides for the future of this country, the nation's civil space program *should* receive funding support of this general magnitude.

If the program cannot receive support from the Administration and Congress at this level, then the achievement of goals of the manned exploration program should be delayed, and the magnitude of the Mission to Planet Earth reduced. Continuing to strive for ambitious goals with inadequate resources will only lead to continuing overcommitment. The Committee suggests, therefore, that unless resources on the order of 10 percent real growth, eventually reaching about 0.4 percent of GNP, can be sustained, then a commensurate scaling back of our space goals and objectives must be undertaken in accordance with the priorities described.

More importantly, however, the Committee believes that the progress of any program with the ultimate, long-term objective of human exploration of Mars should be tailored to the availability of funding — and not to some fixed date for accomplishment. This is not only because we cannot exactly predict costs, or the rate of progress of the revolutionary technology that will be required, but because we must ultimately limit the risk to pioneering astronauts. Clearly, their safety is of greater concern than meeting any challenging, but in truth arbitrary, schedule.

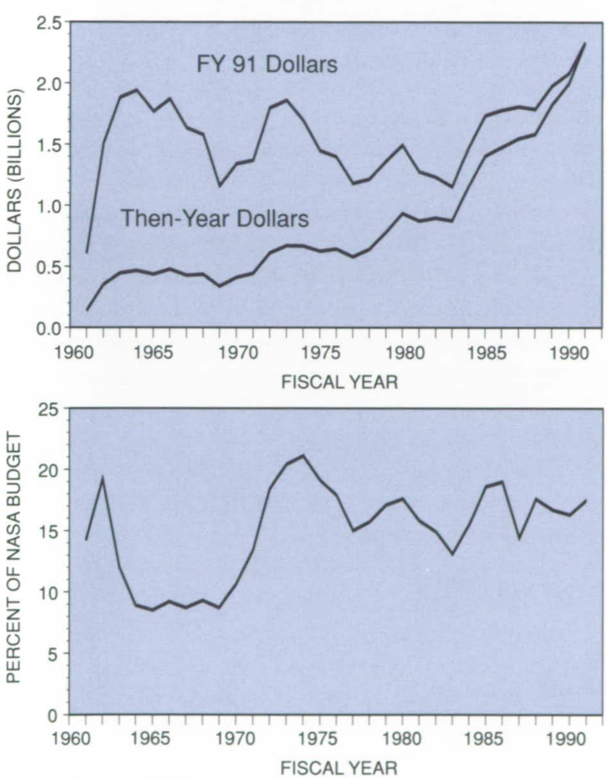
Program Content

For purposes of assessment, the civil space program can be categorized into space science, Mission *to* Planet Earth, Mission *from* Planet Earth, technology and launch systems. The following sections address these topics.

Space Science. American scientists and engineers have used opportunities for access to space to advance human understanding of ourselves, our planet, our solar system, and our universe — from the discovery of the Van Allen belts to the establishment of X-ray astronomy, from the high resolution photos of the planets, their satellites, and rings to the global weather monitoring and forecasting system, from the growth in a microgravity environment of very large crystals to the age-dating of the Moon with lunar samples, from the detailed mapping of the Earth's polar ozone depletions to the precise measurement of the "Big Bang" residual radiation, from the discovery of the effects of microgravity on bone growth and healing in mammals to direct measurements of million-degree solar system plasmas, and from the discovery of the enigmatic, rare repeating gamma ray bursters to the finding of ancient and active volcanoes on other planets and satellites. These achievements and the understanding gained from them will continue to be one of the most significant products of the nation's investment in the civil space program. The cost of this effort, in recent years, has been on the order of 20 percent of NASA's budget (Figure 7).

Figure 7

NASA Space Science Spending



Source: NASA

With so spectacular a set of achievements as a foundation, and with a substantial number of space projects underway, the U.S. space research enterprise should be healthy and flourishing. Yet discussions with researchers within NASA and in the university community reveal that there is significant discontent and unease about what the future may hold for U.S. space research. The reasons for these concerns have been documented in some detail in the 1986 report entitled "The Crisis in Space and Earth Science" issued by the NASA Advisory Council. They include such factors as (a) the widening of research horizons in response to past accomplishments so that there are now more opportunities than can be accommodated by the available resources; (b) the space technology required to support new advances is often more costly and sophisticated than in the past; (c) the growing complexity of interactions between NASA and its larger and more diverse research community; and (d) program stretch-outs, delays and cancellations that waste creative researchers' time, squander resources, and decrease flight opportunities. We believe that many of these reasons continue to exist.

An underlying basis for the concern of the research community has been that the strategies, goals, objectives, and programmatic requirements of the research program have not been adequately distinguished from the parallel national objective of placing humans in space.

Mechanisms are needed which alleviate the more serious of these problems so that the talents and capabilities of America's space researchers, both inside and outside of NASA, can be focused on substantive future opportunities. We strongly affirm the central role of research in the U.S. civil space program, hence —

***Recommendation 1:* That the civil space science program should have first priority for NASA resources, and continue to be funded at approximately the same percentage of the NASA budget as at present (about 20 percent).**

We note that this recommendation carries with it the responsibility for the research community and NASA to use these resources in a prudent manner to carry out pioneering research. To do this, the research community must understand and appreciate, as well as participate in, the planning and budgetary process. To facilitate execution of this recommendation, we propose —

***Recommendation 2:* That, with respect to program content, the existing strategic plan for science and applications research proposed by NASA with input from the science community be funded and executed.**

The present strategic plan provides appropriate balance to the research program that must be maintained across the disciplines, as well as across the methodologies for carrying out the research. In particular, an appropriate mix must be achieved among small, medium, and large projects. A trend toward the development of large projects has developed in recent years, driven by several factors. These include the natural evolution in requirements of some research fields and the "new start" process employed by NASA, the Office of Management and Budget and the Congress for initiating projects to carry out research. This latter process sometimes encourages a "piling-on" of research objectives, as well as of researchers, in order to strengthen fiscal justification. An environment needs to be created that will encourage small, fast-paced projects as well as large projects and enable both to flourish.

Research support activities, such as mission operations and data analysis programs, as well as many portions of the advanced technology development program, represent the life blood of civil space research. These activities, together with sub-orbital balloon and rocket projects, are the centerpiece of university professor and student involvement with the civil space program. Such activities encourage substantial numbers of scientists and engineers, beyond those involved in hardware development for major space flight projects, to participate constructively and creatively in the space program.

We conclude, therefore, that Research and Analysis Programs, Mission Operations and Data Analysis Programs, and the Advanced Technology Development Programs should be viewed as equally essential to the overall research program as are hardware projects themselves; that a "fast track" procurement process be devised for such programs; and that the resources allocated to these support activities not be used as "contingency" resources for unexpected problems encountered on large flight projects.

We view the overall management of the research program to be a key part of the responsibilities of NASA headquarters, and consider that the portion of this activity aimed at the outside research and engineering community can be strengthened. Such strengthening includes a reappraisal of the balance between work performed in academia and that performed within NASA itself. At present, the process that allocates and transfers resources to non-NASA institutions can cause the university community to be at a disadvantage with respect to NASA center researchers and center-funded contractors, the latter sometimes having "umbrella" type contracts for research support to the centers.

We urge that universities, other organizations, and their investigator teams be used increasingly as "prime" contractors for space research instruments and projects.

We recognize that the implementation of this recommendation will vary from one research discipline to another, as well as from project to project. But we submit that its implementation will considerably lessen the reporting burdens now required of researchers, will relieve NASA personnel of certain routine contract coordination functions, and will place the responsibility for the ultimate success of programs that fall into this category where it should be: squarely with the investigator team.

Mission to Planet Earth. NASA's Mission to Planet Earth includes the Earth Probes series, the Earth Observing System (EOS) and the EOS Data and Information System (EOSDIS) and geostationary platforms. The mission promises a major step in the development of the science and technology of global remote sensing of our planet. The data that will be collected in the program are essential for documenting, understanding, and predicting global change. The enormous benefits of this information to society require that NASA ensure that the program is well designed and efficiently managed. Interagency and international contributions and cooperation will be key factors in the success of the program. Data management is of critical importance, as with most space programs.

NASA planning for EOS as a contributor to the U.S. Global Change Research Program was reviewed by the National Research Council in early 1990 and found to be generally consistent with the scientific requirements of that program. However, the review also notes several issues that remain to be addressed. Our Committee emphasizes the importance of NASA's Earth Probes program, which includes smaller, precursor missions to EOS and missions complementary to and contemporaneous with EOS. The Committee also emphasizes the importance of adequate funding for the evolution and operation of the EOS data and information system.

As regards design of the Earth Observing System, the Committee supports the concept of simultaneous flight of instruments to address natural processes occurring on short time scales, and to facilitate intercalibration and environmental corrections. This approach leads to the requirement for a large spacecraft — which is less costly on a per instrument basis. NASA has thus proposed two series of relatively large platforms in polar orbit to implement EOS over a 15-year period.

The NRC report mentioned above generally supports the concept of simultaneity for a group of instruments, the accompanying need for at least one large spacecraft, and the general concept of long-term measurements. But the report also notes that many objectives could perhaps be achieved better and sooner with a series of smaller, independent satellites. Moreover, the Committee notes that the perception remains in the scientific community that the current proposal of a fixed configuration of two relatively large polar platforms may not be ideal for answering important questions yet to be clearly posed. Furthermore, compromises have to be made when many instruments fly on the same platform, and failures can lead to massive loss of data. Continuity and reliability of the data stream also are key factors for understanding global change, as is the considerable contribution of non-U.S. Earth-observing activities.

The Committee sees no reason to disagree with the NRC report, and concludes that the design of EOS must involve a variety of different spacecraft to meet so complex a set of requirements. In the end, a combination of different size spacecraft and surface-based platforms will be needed. Alternative approaches should be carefully examined so that the optimum approach can be selected to meet scientific objectives with continuity, reliability, and affordability. Particular diligence will be required to assure that the complexity of EOS is controlled.

Data from environmental satellites operated by the NOAA, the Department of Defense and EOSAT all provide basic environmental information valuable to the Mission to Planet Earth. NASA's coordination with these ongoing programs is an essential element of the civil space program.

The Committee recognizes that NASA's charter includes the development of new space capabilities, including remote sensing systems for environmental monitoring, but notes that NASA's role in the research and development for operational environmental satellites has diminished in recent years. In our view, this trend should be reversed. We note that EOS and other components of Mission to Planet Earth can serve as a valuable testing ground for pre-operational instruments. Thus —

Recommendation 3: **That the multi-decade set of projects known as Mission to Planet Earth be conducted as a continually evolving program rather than as a mission whose design is frozen in time. A combination of different size spacecraft appears to be most appropriate to meet the needs of simultaneity, accuracy, continuity and robustness. NASA also should re-establish research and development in support of environmental satellites to meet NOAA-stated requirements. NOAA, for its part, must budget adequately to finance the operational costs of spacecraft and instruments, as well as related day-to-day support activities.**

The Earth Observing System combines the characteristics of research and operational missions. The overall importance of the program to the nation and its dual character taken together enforce the need for high-level management attention. Moreover, considering that EOS will be the centerpiece, at least in terms of resources, for the U.S. Global Change Research Program, it is essential that the planning and decision making process encompass the full range of relevant agencies and the federal Committee on Earth and Environmental Sciences (CEES). The large size, broad scope and national importance of the program also suggest that the EOS funding be provided as a line item, separate from other science programs. This overall undertaking demands continued attention at the policy level by the National Space Council.

The Committee believes that a review of the decision-making process for Mission to Planet Earth, including its relation to the U.S. Global Change Research Program, should be carried out for the National Space Council by a group from government, industry and academia, headed by the Director of the Office of Science and Technology Policy (OSTP). The review should consider interagency aspects, the role of the CEES, and international dimensions, and make recommendations aimed at ensuring the success and continuity of the program.

It has been proposed to the Committee that the current civil operational satellites, including NOAA environmental satellites and Landsat, could be operated more efficiently and cost-effectively if aggregated under a single commercial entity (especially when considered on a global basis). In this case, the federal government would access the data it requires and carry out the needed research and development, rather than actually operating the satellites. The international dimension is of clear interest in that it might be possible to develop an international consortium for remote sensing similar to Intelsat or Inmarsat.

Consequently, the Committee urges that the National Space Council, together with OSTP and OMB, undertake a feasibility study to determine if a single commercial entity could provide more cost-effective management for operational environmental and land remote-sensing satellites. The prospects for an international consortium should be evaluated.

NASA's experimental Landsat program was transferred to the Commerce Department in 1983 with the expectation that the operation could be commercialized profitably. Virtually all parties to that expectation now agree, and international experiences verify, that full commercialization of Landsat is not feasible for the foreseeable future.

Moreover, the funding required to sustain the transfer has been subject to an annual threat of termination. Action must be taken to remedy this problem, or the U.S. shall lose both this important data and leadership in remote sensing — the latter already under serious challenge.

Mission from Planet Earth. On July 20, 1989, the 20th Anniversary of the Apollo 11 Moon landing, President Bush proposed that the nation commit to a "sustained program of manned exploration of the solar system," thereby initiating what has come to be called the Space Exploration Initiative (SEI). In his remarks, the President recognized the Apollo program and all those who contributed to it, but also noted the transient nature of that program and the necessity not to be constrained to "brief encounters" in our future space exploration activities. Thus, the Space Exploration Initiative consists of robotic missions to the Moon and Mars, as well as the establishment of permanent outposts (not necessarily continuously inhabited) on the Moon and, later, human exploration of Mars.

At some point, it will be necessary to set a specific date for the return to the Moon and, later, for the initial Mars landing. We believe that such a date can best be established at some future time. There is much planning yet to be done, enabling technologies be developed, key questions to be answered in the area of life sciences, and funding constraints to address. The question might then be asked: "If there is no timetable for the Mars landing, why is it necessary to establish a program and a set of goals at all?" We believe the answer is several-fold. First, any large organization, such as NASA, generally works best when it has an overarching and challenging objective to guide its long-term future. This provides a focus and rationale for the large series of otherwise somewhat disconnected technological efforts which not only enable the eventual program, but also offer the resulting developments to all of our nation's space and non-space activities. Further, the existence of a long-term and evident goal helps make real the work of researchers and technologists — not to mention helping motivate talented young men and women to join NASA.

It is possible, of course, to conceive of a space program without a long-term vision such as the human exploration of Mars; significant science would still be accomplished and the Earth's environment would still be monitored. But we would lose the jewel represented by the vision of a seemingly unattainable goal, the technologies engendered, and the motivation provided to our nation's scientists and engineers, its laboratories and industries, its students and its citizens. Hence —

Recommendation 4: **That the Mission from Planet Earth be established with the long-term goal of human exploration of Mars, underpinned by an effort to produce significant advances in space transportation and space life sciences.**

Recommendation 5: **That the Mission from Planet Earth be configured to an open-ended schedule, tailored to match the availability of funds.**

To respond to this long-range exploration challenge, NASA must establish the framework within which to develop at least six new technology bases and program elements: (1) a modern economical heavy lift launch vehicle; (2) a life sciences emphasis space station; (3) affordable, evolutionary interplanetary transportation systems; (4) automated lunar and Martian exploration; (5) extraterrestrial resource utilization systems; and (6) reliable closed loop ecological life support systems. The planning for this undertaking will be a challenge that will require adequate time and, most important, outstanding human resources. Later in this report we suggest that a new position, Associate Administrator for Exploration, be established. This person, supported by his or her own Conceptual Systems Design team, should be responsible for planning, overseeing and integrating the six new technology bases and program elements required to carry out the Mission from Planet Earth. The first task must be to prepare an evolutionary, flexible long-range plan that starts with 21st Century operations on Mars and works backward to critical initial steps and realistic budgets. Immediate attention must be given to establishing a vigorous new space life sciences program, and eventually to planning for international participation in the Mission from Planet Earth.

Space Station Freedom. We have elected to treat Space Station Freedom as the first step in the Mission from Planet Earth even though it has other valid uses, such as hands-on extended duration microgravity research. The latter may have important impact in the area of competitiveness, potentially unlocking new developments in such fields as materials, electronics and biosciences.

Space Station Freedom has now been in the design and development phase for three years and, if one includes the concept formulation phases, for eight years. Approximately $3.6 billion has been expended on the project to date. Nonetheless, debate continues over its design concept and even its basic purpose. This has been exacerbated by concerns over the ability of the Space Shuttle to support Space Station Freedom. As of October, 1990, the baseline plan for the initial block of Space Station Freedom required 18 Shuttle launches over roughly a four-year period, plus five logistics launches per year once the station is permanently occupied (five flights prior to the completion of the initial block).

Aside from its role in life sciences, it does not appear to the Committee that any manned space station can be justified based solely upon the science it enables — nor has this been claimed in the case of Space Station Freedom. Microgravity research is a significant and promising field of endeavor, although of unknown potential. It justifies some form of space platform for experimentation, but it is not, of itself, a sufficient justification for a manned space station.

Likewise, we do not find compelling the case that a space station is needed as a transportation node for planetary exploration. First, many promising flight profiles do not appear to require such a node and, second, if they did, the need in our judgment is sufficiently far in the future that we would hardly know today what to ask of such a terminal today.

On the other hand, the Committee holds the strong conviction that if the U.S. is to have any significant long-term manned space program, a space station is the next logical and essential element of that endeavor. The most significant unknowns remaining in manned exploration reside in the area of life sciences. A manned, near-Earth laboratory is, in our judgment, the sensible place to begin addressing these crucial questions which sooner or later must and will be resolved — by the U.S. or some other spacefaring nation.

The need for the Space Station thus rests squarely upon life sciences experimentation and the development and verification of long duration space operating systems. These, together with its uses for microgravity research and applications are, in our opinion, a more than sufficient justification for a space station. A space station is needed specifically to establish effective strategies to prevent or mitigate the debilitating deconditioning effects on humans of long stays in low gravity fields, and to establish absolutely reliable and efficient life support systems for extended human stays in unforgiving, hostile environments. A space station also can push the development and verification of durable robotic systems to monitor, maintain and repair complex hardware systems in such environments. Finally, a space station can provide essential experience in the effective operation of large, technically sophisticated remote-from-Earth inhabited outposts.

But do these needs demand a space station of the complexity of Space Station Freedom, particularly given the limitation which has been imposed on funds for its development? Our answer, reluctantly, is that they do not. We say reluctantly because one of the most debilitating diseases a space program can acquire is a tendency to keep stopping and restarting in search of the ever elusive ideal solution — and we are disinclined to contribute to any such process. On the other hand, we concur that a modified design, along the general lines NASA is now considering, is mandatory. Thus, we propose —

Recommendation 6: **That NASA, in concert with its international partners, reconfigure and reschedule the Space Station Freedom with only two missions in mind: first, life sciences experimentation (including the accrual of operational experience on very long duration human activities in space) and, second, microgravity research and applications. In so doing, steps should be taken to reduce the station's size and complexity, permit greater end-to-end testing prior to launch, reduce transportation requirements, reduce extra-vehicular assembly and maintenance, and, where it can be done without affecting safety, reduce cost. The planned ninety days may prove an inadequate period of time to conduct so significant a reassessment. Such time as is required should be taken.**

The Committee believes that, wherever possible, integrated systems should be fully tested and verified on the ground. For example, the habitat and experimental modules should be tested and verified in their furnished and operational mode before launch. Systems that cannot be fully verified in one-g should be tested and verified on orbit before permanent human occupancy.

In addition, an assured crew return capability for use in an emergency must also be operational prior to permanent human occupancy. Finally, reasonable margins in weight, power, crew assembly time, and crew maintenance time must be provided.

Although warranting reconfiguration and probably rescheduling, the Space Station remains, in our judgment, the essential initial building block of the manned exploration program.

The next goal for the manned exploration program is the establishment of permanent (although not necessarily continually inhabited) outposts on the Moon. This step is needed to learn how to live and work on the surface of an alien planet, but will also provide opportunities for geological and astronomical research. Particularly important will be the testing of habitats, closed ecological life support systems, and remote space-rated power plants; learning to process and use indigenous materials; observing the effects of living in extreme heat, cold and dust in low-gravity fields; and developing reliable systems to provide radiation protection and surface mobility for humans and robots through 300 hour-long days and nights.

The Moon's surface contains records of the ancient bombardment phase of planetary evolution in the solar system. Its cratered surface can tell us much about the Earth during the formative stages of the atmosphere and oceans. Erosion and plate tectonics have erased almost all evidence of this era from our planet. Lunar mineralogy, geochemistry, and stratigraphy on the front and far side of the Moon, with its diverse lava flows and mass concentrations, are fertile fields for research in comparative planetology. The Moon's relationship to the Earth while our planet was forming may be discernable on the Moon. Many serendipitous discoveries will almost certainly be made, perhaps similar to the finding of meteorites in Antarctica.

While substantial knowledge has been gained about the Moon and Mars over the history of space exploration, unknowns still pose questions and potential risks to intensive human exploration, unknowns such as the high latitude geography of the Moon, the concentration of water and useful minerals in Mars soil, etc. Some robotic reconnaissance or prospector missions will need to be defined and executed prior to manned explorations. There are also life sciences and space physics missions that may be necessary. Thus we propose —

Recommendation 7: **That technology be pursued which will enable a permanent, possibly man-tended outpost to be established on the Moon for the purposes of exploration and for the development of the experience base required for the eventual human exploration of Mars. That NASA should initiate studies of robotic precursor missions and lunar outposts.**

Interplanetary Transportation. Eventually it will be necessary to provide affordable transport to the Moon that can evolve later to extend space flight to Mars. A NASA sponsored "Synthesis Group" is currently investigating alternatives for these missions. Candidate conceptual system designs include automated electric propulsion/aerobraking cargo carriers, and modular space-based transfer vehicles with hydrogen-oxygen engines and aerobraking shields. Economical cargo transport beyond Earth orbit also is in prospect using low thrust, high specific impulse solar or nuclear thermal propulsion systems — with the propulsion-energy generators adding to the useful delivered payloads.

Exploration Bases. The lunar program will be needed to gain experience in establishing and operating bases on remote bodies and to eventually understand how to live and work on the surface of an alien planet. Lunar and Martian habitation will also call for improved space suits; solar and nuclear electric generators in the 10 to 100 megawatt range; decentralized computers; automated plants to process indigenous materials; robotic construction machinery; and transportation and communication facilities. Lunar base prototype systems should be designed for adaptability to Martian conditions.

Closed Loop Ecological Life Support. New, closed ecological life support systems (CELSS) will be necessary to sustain people living in extra-terrestrial bases. Air and water must be recycled, and nourishing food produced within automated closed-cycle support systems. Air and water recycling is relatively straightforward, but little is known about constructing reliable biospheres that can be depended upon for continuous automated production of food and organic materials, and the removal of toxins and contaminants. This is an excellent field for US-USSR cooperative effort involving multi-disciplinary government and university laboratories. Of all the critical elements for long duration space flight, closed ecological systems remain among the least understood, and the most challenging.

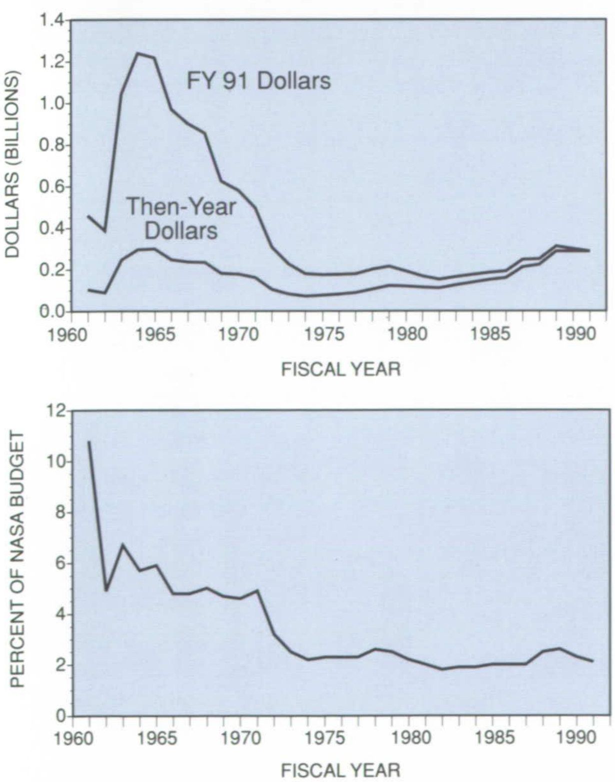
Space Technology. Unlike research, which seeks new knowledge, technology is concerned with the application of that knowledge to useful purposes. The development of advanced technology is thus crucial to the success of the exploration and exploitation of space — whether human or robotic. Since NASA is a major consumer of space products, NASA bears part of the responsibility to assure the viability of the technology base upon which to build the missions of the future.

The serious technological challenge for NASA at the present time does not relate to issues of invention or creativity, but rather to the difficult sequence of taking an invention and turning it into an engineered component, testing its suitability in space; and then incorporating it into a spacecraft system. In its early years, NASA managed this "technology insertion" phase particularly well. But there is a widely-held opinion that although NASA continues to do excellent research, both in its centers and in its affiliated universities, the results of this work are not being efficiently transferred into applications — a fault, it must be said, that is shared with U.S. industry at large. A prime responsibility of the NASA technology development activity must be to bridge the gap between technology concepts and application to space practice. Prototype developments can be particularly important in this regard.

Unfortunately, NASA has not been permitted to sustain an adequate level-of-effort program in space technology due in recent years to externally imposed budget reductions (Figure 8). We believe that this is a consequence of a lack of appreciation of the key role that technology development plays in enabling future missions, reducing future systems' costs and increasing America's competitiveness. It has, of course, been suggested from time to time that the budget for these activities is not spent effectively. Moreover, since most of the funding is expended within NASA, the university or industry constituency to provide political support for the program is limited. Both of these concerns can be alleviated if technology development programs are made competitive, such that they involve the best talent

Figure 8

NASA Space Technology Spending



Source: NASA

wherever it may reside — including in other government agencies where appropriate. In any event, this under investing trend must be reversed. If the nation is to successfully undertake challenging space initiatives in the future, we must reestablish our technology base today.

Among the more critical technology topics that must be pursued are propulsion and aerodynamics including flight evaluations, advanced rocket engines that do not detrimentally impact our environment, aerobraking for orbital transfer, long duration closed ecosystems and life support systems, nuclear-electric space power, space tethers and artificial gravity, automation and robotics, information management systems, sensors, electric power generation, radiation protection and materials and in-space materials processing.

Technology development can be considered in three phases, each of which warrants attention. The first is advanced and/or generic technology that may have broad applicability, such as innovations in data management and storage. The second is technology tied to specific programs, such as nuclear propulsion for the exploration program. The third consists of flight qualification of new technology. Each of these aspects needs to be handled in a different manner.

In particular, we believe that technology which may have generic applicability should be developed under the auspices of the Associate Administrator responsible for advanced technology. The accompanying planning effort should involve other appropriate Associate Administrators having responsibilities for major future missions. These concerns lead us to —

Recommendation 8: **That NASA, in concert with the Office of Management and Budget and appropriate Congressional committees, establish an augmented and reasonably stable share of NASA's total budget that is allocated to advanced technology development. A two- to three-fold enhancement of the current modest budget seems not unreasonable. In addition, we recommend that an agency-wide technology plan be developed with inputs from the Associate Administrators responsible for the major development programs, and that NASA utilize an expert, outside review process, managed from headquarters, to assist in the allocation of technology funds.**

On a related issue, the Committee is particularly concerned over the low priority that has been given to the development of the life support technologies, and to the fundamental medical aspects of long duration space flight by humans. The scientific community and NASA are now in substantial agreement as to the steps that must to be taken to redress this shortcoming. However, responsibility for the conduct of research on these issues, which could affect the fundamental feasibility of space exploration by humans, currently is split between the Office of Space Science and Applications and the Office of Aeronautics, Exploration and Technology — as well as between two principal centers and several supporting centers. Such fragmentation is debilitating to what should be an urgent and focused research and development program. All flight-related life sciences research that is pursued should be considered technology development, and treated as such within the NASA organizational structure.

The Associate Administrator for Exploration suggested later should be given the authority and responsibility for space human biology activities. Further, we advise that work in this important area be consolidated as far as possible into a single center, with research being contracted on a competitive basis wherever feasible.

Space Infrastructure

Space Transportation Systems. The most fundamental building block without which there can be no future space program is the transportation system which provides our access to space. All spacecraft and mission architectures are constrained by the characteristics of the vehicles that lift them into orbit. When things are going well in space transportation, the space program seems to flourish; when space transportation is troubled, the entire space program languishes and any other error seemingly is magnified.

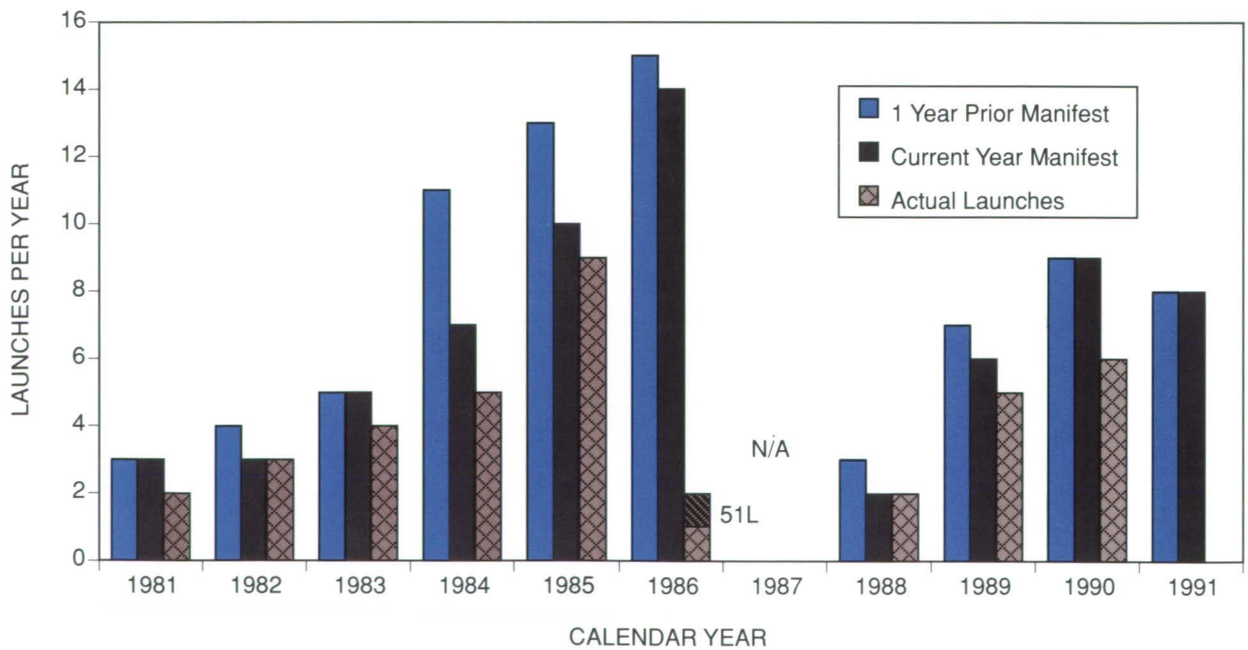
The Committee finds that the most significant deficiency in the nation's future civil space program is an insufficiency of reliable, flexible and efficient space launch capability. The nation now needs to move ahead and attain a more robust launch capability.

Along with its impressive and unique capabilities, the Space Shuttle has shown itself to be a complex system that is expensive to operate and whose emergence from developmental status has not yet taken place (Figure 9). The presence of the crew adds to its cost and perceived risk. The combination of these factors drives manpower requirements up, complicates payload design, and brings about the high cost of its operation (Figure 10). Planned mission frequencies which are realistic and achievable are considered by the Committee to be essential to cost containment.

The nation is at a critical juncture as we look ahead to consider how future space endeavors will be influenced and limited by what we decide now about Earth-to-orbit transportation. There is general agreement in all recent space transportation studies (e.g., the Defense Science Board and the

Figure 9

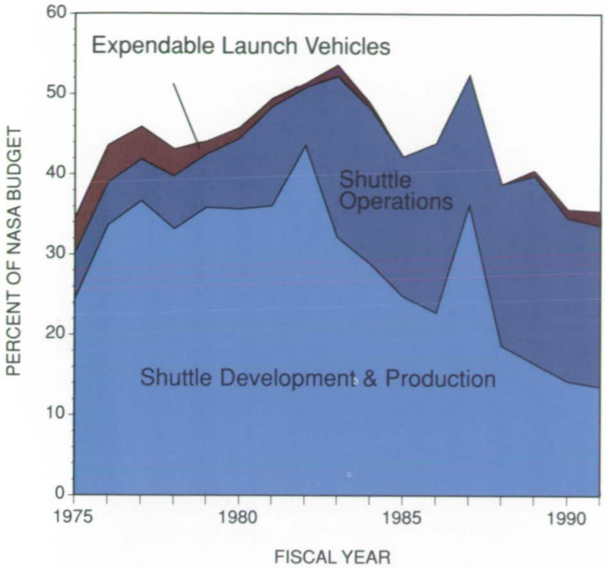
Shuttle Launch Operations Planning and Realization



Source: NASA

Figure 10

NASA Space Transportation Spending



Source: NASA

NASA Advisory Council studies) that the nation needs a new heavy lift launch capability, but no implementing decision has resulted. These reports, combined with our concern about the heavy dependence upon the Shuttle, point to the unalterable need for the initiation of a major national effort to develop a new launch system that can provide a flexible heavy lift capacity. Not only will an evolving space station need heavy lift support, but other missions also will benefit from reduced dependence upon the Space Shuttle.

The first goal for a new Expendable Launch Vehicle (ELV) system should be to augment support of the Space Station. While the Shuttle might carry out some early Space Station deployment, alternative transportation should significantly reduce the cost and risk of that program. The time to make a commitment to this end is now, for the longer the nation delays the building of a new launch system, the greater is the risk that it will embark upon a space station and a subsequent manned exploration program that eventually could prove unsupportable.

There is a range of choices available for a heavy lift vehicle (*circa* 150,000 pounds to near-Earth orbit). One candidate would be some form of a Space Shuttle-derived ELV, but there are others. At the extremes, a dilemma lies in choosing between starting the heavy lift system design from a "clean sheet," or selecting a design closely related to the current Shuttle (e.g., a Shuttle-C). The latter provides an earlier capability with less initial cost, but the former provides an opportunity for the revolutionary design of a completely new launch system incorporating up-to-date propulsion and support system technology. Assessment of the economics, the lack of firm Department of Defense requirements, the need to further define lunar/Mars payloads, the status of advanced launch system technologies, and long propulsion lead times are all important considerations as the choices are weighed.

On balance, the Committee concludes that the prudent choice — with an eye toward both the Space Station and the long view — is an approach that begins with a new ELV system that meets the following criteria:

- Operational capability must be achieved in time to support at least the latter stages of Space Station deployment and relieve its Shuttle dependence as soon as feasible.
- Launch support manpower must be reduced.
- Provision should be made for updating with new components as they become available from the joint NASA-DOD Advanced Launch System (ALS) technology development. In particular, the Space Transportation Main Engine should be introduced into the new launch system at the earliest appropriate time.

This should be the first phase of a continuing effort to upgrade Earth-to-orbit transportation. Some time hence, further advancements in lift capability can be achieved when justified by requirements and technical developments. In particular, this second phase should involve ongoing application of technologies developed in the ALS program, and should lead to the design of an advanced launch vehicle and support system of enhanced efficiency and reliability.

The Committee believes that the U.S. should not plan to depend on any foreign launch capability (such as the Soviet Energia, as some have proposed) to support critical U.S. space programs.

The following summarize our conclusions with respect to launch capability —

Recommendation 9: **That the Administration promptly establish and fund a firm program for development of an evolutionary, unmanned but man-rateable, heavy lift launch vehicle. This system should reach operational capability in time to support all but the initial phase of the Space Station deployment.**

NASA and the Air Force should continue a vigorous Advanced Launch System technology program to support both near-term and follow-on heavy lift requirements. Highest priority in the launch vehicle technology effort should be assigned to the Space Transportation Main Engine (STME). Once a better definition of the lunar and Mars architecture and mission requirements is established, this advanced technology can be infused into a new vehicle design.

In the meantime, because of continued dependence upon the Space Shuttle, NASA should execute its plan to enhance the reliability and safety of this vehicle and to reduce launch costs. The examination already underway of the launch preparation process should be pursued with vigor. Consideration should be given to the possibility that a stable flight rate planning factor including greater margins might, of itself, facilitate the implementation of cost (manpower) savings.

The issue has arisen as to whether NASA should procure another Space Shuttle Orbiter to provide a more robust five-vehicle fleet. The Committee does not support such a procurement at this time. The Committee appreciates that we may lose another orbiter before the proposed new unmanned heavy lift launch vehicle is completely developed, and that this would once again result in a fleet of only three operational Space Shuttles, as has been the case since 1986. But, as of the present, we conclude that any decision to procure another orbiter should be deferred and funding for the unmanned launch vehicle given priority. In the meantime, the current NASA practice of procuring structural spares should continue in support of the existing Space Shuttle fleet.

***Recommendation 10:* The Committee recommends that the procurement of an additional Space Shuttle orbiter, for a five-orbiter fleet operation, not be undertaken at this time, but spares procurement should continue. If an orbiter is lost in the relatively near future, the decision on whether to procure another orbiter should be made in the context of the availability of the new heavy lift launch vehicle and the demands on the remaining orbiter fleet.**

Alternate Personnel Transportation. The emergency recovery capability now planned for the Space Station is essential. However, with the exception of the crew recovery system, plans do not now call for a fully redundant personnel transportation capability to assure that manned activity can continue if the Space Shuttle is grounded for an extended period. In light of this situation, the Committee believes a rescue vehicle should be designed and, as a contingency, provision made for expedited development of a two-way transportation capability on a man-rateable ELV for use in the event of a Space Shuttle stand-down. Although full two-way capability may be neither affordable nor practical in the near-term, design and development of an emergency recovery system can protect an option for later expansion to provide a two-way capability on an expedited basis. This or some other approach to a redundant personnel transportation, to which NASA could turn in the circumstance posed, is regarded as worthy of attention.

***Recommendation 11:* That NASA initiate design effort so that manned activity in the Space Station could be supported in the absence of the Space Shuttle. Crew recovery capability must be available immediately, and provision made for the relatively rapid introduction of a two-way personnel transport module on a selected expendable launch vehicle.**

National Aero Space Plane (NASP). It would be premature at this point to expect the NASP to play a contributing operational role in Space Station or other orbital support missions for the next 15 to 20 years. Nevertheless, the long-term potential for this unique combination of aerospace technologies could be significant. Use of the hypersonic air-breathing propulsion technique for acceleration of space qualified vehicles as an upper stage from high subsonic to orbital velocities offers altogether new capabilities. Once in orbit, such platforms might dip into the atmosphere and use their aerodynamic properties to generate an orbital plane change, then be boosted back into orbit by the scramjet engine using the atmosphere to supply the needed oxygen.

In spite of the NASP's long-term potential, the Committee generally endorses the view of the Defense Science Board which, in March, 1990, suggested that, at least in the foreseeable future, the NASP's single-stage-to-orbit concept may have been over-emphasized. The more important aspect of this program is its development of air-breathing hypersonic propulsion capability.

Even so, the relatively modest expenditures needed to move the NASP initiative briskly forward towards a technology demonstration flight program with an X-vehicle are worthwhile, given the potential for a major breakthrough capability. This is exactly the kind of revolutionary program NASA should undertake, although we do not assign it high schedule urgency.

Management

We believe that the management hierarchy of the Civil Space Program, within the Executive Branch should be: the National Space Council, to provide policy direction; NASA headquarters, to provide executive management; project offices to provide specific project direction; and centers to offer day-to-day program implementation and supervision of supporting contractors from the private sector and academia.

Various models were examined by the Committee whereby major responsibilities might be shifted from NASA to other organizations, somewhat along the lines of the Department of Defense's Strategic Defense Initiative Organization, government corporations, the Department of Energy Laboratories, etc. With the possible exception of the expanded use of Federally Funded Contract Research and Development Centers, discussed later, the Committee believes that such action would be counterproductive. The fact is that NASA remains the world's greatest repository of space knowledge and experience. Thus, efforts should be devoted to its improvement, not its dismemberment. The Committee concludes —

That NASA should continue to be the nation's principal agent for carrying out its civil space program, under policy guidance from the Space Council, and drawing as appropriate on other government resources and the capabilities of the private sector and academia.

External Oversight. No examination of civil space management issues can consider NASA in isolation, because numerous interfaces exist with other parts of the government, many of which, by law, enable policy direction, funding, management constraints and oversight. Much of this infrastructure has existed since the formation of NASA, including legislative oversight and the existence of a National Space Council, originally mandated by the National Aeronautics and Space Act of 1958. But 30 years of executive and legislative change have taken their toll on the smoothness of many of these interfaces.

In the heady days of the early space program, with its emphasis on catching and surpassing the Soviet space program, NASA was afforded extraordinary latitude by the Congress. Exceptions were made to the generally applicable civil service regulations to permit NASA to attract and retain the very best of the nation's technical talent. Financial and budgetary controls were designed to give the Administrator the flexibility to operate fast-moving programs, e.g., "no-year" funding. Similarly, the agency was granted important powers for procurement, unfettered by such later controls as, for example, the act which now places stringent constraints on the agency's ability to acquire computer systems.

Executive Branch. Over the years, policy guidance to NASA, and the integration of NASA activities with other technological, scientific, political and national security responsibilities of the U.S. government, have been accomplished in a variety of ways. The management process has now come full circle — to a new National Space Council, re-enacted in 1988 and implemented by Executive Order on 1 March 1989. Prior to the establishment of this new Council, the policy generation mechanism was a combination of a Senior Interagency Group (SIG-Space) and a working group of the Economic Policy Council — an arrangement that most considered unsatisfactory.

Various ad hoc groups have wrestled with the matter of setting space policy. One of the more thoughtful recent analyses was conducted by the Center for Strategic and International Studies. This study recommended that the NASA Administrator also serve as Director of Civil Space (DCS— somewhat equivalent to the Director of Central Intelligence (DCI) in the intelligence community). While implementation of this proposal would not change the role of the Space Council, it would accentuate the important role the head of NASA could and should perform in *assisting* with the establishment of overall policy, coordinating vital national security interfaces, and integrating all civil space activities (Figure 11). This arrangement recognizes that virtually no governmental civil space pursuit can succeed without the support and participation of NASA, but it also recognizes the importance of coordination with the space endeavors of other government agencies. Indeed, as applications of space capabilities increase, coordination will become more and more essential.

Although the "DCS concept" has many attractive aspects, we do not believe that it has received sufficient scrutiny to warrant endorsement at this time. Instead, we propose it for consideration by the Vice President in his role as Chairman of the Space Council.

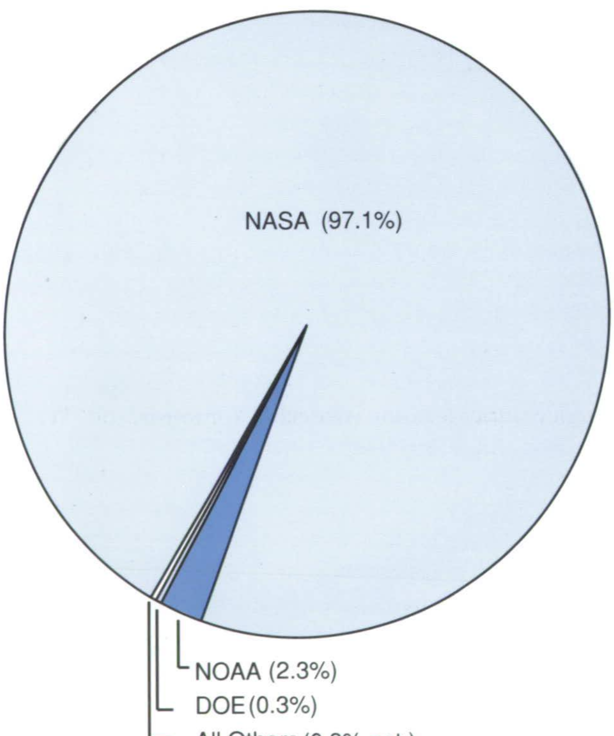
We are also persuaded that the membership of the Space Council, as provided for in the Executive Order of 20 April 1989, is sufficiently large that its treatment of many relatively routine issues could be facilitated by the establishment of an executive committee. Hence—

Recommendation 12: **That a Space Council Executive Committee, chaired by the Vice President and consisting of the Administrator of NASA, the Directors of the Office of Management and Budget and the Office of Science and Technology Policy, the Secretary of Defense and the Director of Central Intelligence, be institutionalized. Other Space Council principals should participate in the Space Ex-Comm meetings when appropriate, at the invitation of the Chairman. Major issues would continue to be addressed by the Space Council as a whole.**

The Committee notes also that, because of the increasing potential for contributions by NASA to America's economic competitiveness, it may be appropriate for the Administrator of NASA to serve as a member (or ex-officio member) of The President's Council on Competitiveness.

Figure 11

U.S. Civil Space Program Budget Allocation



1990

Total Civil Space Budget: $11.49 Billion

Source: National Space Council 1990 Report to the President

Legislative Branch. The Committee believes that space program planning and execution could benefit to a significant degree by refinements in Congressional operations related to program approval, resource allocation and oversight. The evident need for greater program stability could be furthered by more comprehensive Congressional debate backed by more accurate programmatic information (especially cost) prior to the time significant commitments are made — and then greater diligence, absent substantive programmatic changes, to preserving planned funding profiles. Such intensified initial examination should focus on the specific justification for objectives, affordability, timing, implementation policies and technical risks. Congress should demand clarification of any proposal or element considered inadequately defined and substantiated, and also devote attention to options and alternatives.

We believe NASA should develop a 10-year plan to provide Congress with sufficient information on objectives and implementation approaches to permit sound initial budget decisions. Most importantly, this plan should provide cost information, based on straightforward and understandable assumptions, including the costs of development, launch and operations.

Once a program is approved, however, the Congress can and should help provide program stability through consistent and adequate funding. The successful management of multi-year development programs is extremely sensitive to this continuity. Thus, we strongly endorse the use of multi-year funding and "no-year" appropriations whenever appropriate, to provide program stability and reduce costs.

Internal Management. The Committee recognizes NASA's past effectiveness in mobilizing government-academia-industry teams to achieve a remarkable set of accomplishments over more than three decades. NASA also has been responsive to a considerable flow of external recommendations, some of which were precipitated by reviews following the Challenger accident. With the implementation of recommended "recovery" steps now substantially completed, however, the Committee has viewed its primary responsibility as that of identifying opportunities that will strengthen NASA's management capabilities for the future.

The Committee strongly believes that the internal management structure of NASA is best determined by those having the ultimate responsibility for the Agency's performance. Therefore, we do not offer firm recommendations in this area. Nevertheless, there are a number of observations that we consider worthy of serious consideration by NASA management, and these are offered below.

Headquarters Functions.

Systems Concepts and Analysis. The Administrator and his senior staff have an increasing need for the provision of both policy formation support and independent analyses, not only in the formulative stages of programs but also as an ongoing review function. Increasingly there will be issues that cut across organizational and programmatic boundaries. Thus, particularly in the early conceptual phases of programs, there will be an increased need for systematic reviews of requirements and benefits. The analysis function proposed below should provide the Administrator with independent expertise to generate and assess alternative approaches to program objectives, and to balance these objectives against overall national goals. The existence of this group of perhaps some 30 highly qualified individuals should also stimulate improved planning and program coherence throughout the agency.

It will be difficult to recruit this senior systems engineering and analysis capability entirely from within NASA given the constraints on personnel transfers, and almost impossible to recruit it from outside of NASA due to the constraints of current civil service salary regulations. Accordingly, we propose —

That a Systems Concepts and Analysis Group be formed in the NASA headquarters to serve the Administrator. This group would consist of a small, elite civil service staff supplemented by a new or existing Federally Funded Research and Development Center (FFRDC). (Item A.)

Such a center could possibly be affiliated with a university, or not-for-profit institution but an industrial affiliation would not be appropriate under most circumstances. The practices of the Department of Defense in using such centers should be considered.

Independent Cost Analysis. NASA as well as other agencies of the government have been embarrassed from time to time by less than accurate estimates of project costs. The causes are well understood, and include program initiation before enabling technology is proven, overselling on the part of program advocates, both in government and industry, and failure to include all costs when evaluating a program. With programs becoming ever more costly and complex, it now appears to be an appropriate time for the Administrator to have access to a highly skilled and independent cost estimating and analysis capability. Again, top-notch specialized personnel will be required, perhaps 20 in number, but in this case recruitment should not be inordinately difficult. However, this group must be capable of utilizing modern approaches for assessing the costs of complex advanced technology systems manufactured under a variety of management and business strategies. In short, we suggest —

That an independent cost analysis group be formed to serve the Administrator and the Administrator's staff. This group should be charged with the responsibility of providing to the Administrator a recommendation on all significant cost estimates provided to the Congress or to the Office of Management and Budget. Their cost estimating procedures should include contingency analysis techniques. (Item B.)

Exploration. Exploration of the solar system, using both unmanned and manned systems, has been and will continue to be a core mission of NASA. Since the nation's first extra-terrestrial probe, Pioneer IV in 1959, exploration activities have been distributed across various NASA Associate Administrators (Science, Manned Space Flight, etc.) While achieving great success in lunar and planetary exploration, we continue to encounter uncertainties regarding the appropriate use of manned vs. robotic exploration, and the legitimacy of science as a rationale for exploration. In reality, exploration will be a continuum of robotic missions preceding the presence of man, and science will continue to be a strong rationale for exploration — but certainly not the only motivation. For these reasons, we believe it is time to consolidate the exploration activities of the agency under a single Associate Administrator. We propose, therefore —

That an Associate Administrator for Exploration be established with responsibility for both robotic and manned exploration of the Moon and Mars, the humans-in-space portion of life sciences studies, and technological foundations for manned and unmanned exploration of the Moon and Mars. (Item C.)

Space Station. The Report of the NASA Management Study Group in 1986 recommended that the Space Shuttle and the Space Station be placed under a single Associate Administrator. This was accomplished in the Office of Space Flight. The rationale for this recommendation was the perceived close interdependence between the Space Shuttle and the Space Station. We have concluded that it is time to reassess that decision. Together, these two programs represent 47 percent of the 1991 NASA budget, but they are in very different phases of their program life cycle, demand different management skills, and impose different pressures for attention upon management. Furthermore, while there are indeed important interfaces between the two programs, the reconfiguration of the Space Station should ensure that these interfaces become relatively more straightforward.

As will be noted in the next section, we suggest that operations be separated from development. Accordingly, we propose that the Space Station program be grouped with other space flight developments such as the Advanced Solid Rocket Motor (ASRM), the Alternate Crew Recovery System (ACRS) and the development of a new heavy lift launch vehicle. With regard to Space Station mission requirements, we suggest that the Associate Administrator for Exploration serve as focal point. Thus, it is proposed —

That the Space Station and other space flight development programs report to a NASA Associate Administrator for Space Flight Development. (Item D.)

Space Flight Operations. The conduct of civil space flight operations, and the dominant role of the Space Shuttle, was raised continually during our deliberations by knowledgeable individuals and groups with strong interest in NASA and the national space program. Their comments frequently referred to the consuming effect this responsibility can have on NASA's senior management, limiting the time available for the planning and direction of leading-edge technological developments. A belief also was expressed that the merging of operations into a largely developmental organization does not foster the building of a professional operations cadre which can best manage this vital responsibility. Solutions proposed for this dilemma included the transfer of Space Shuttle operations to some to-be-determined "other government agency," such as a quasi-government corporation, or to the private sector.

A clear statement of the problem appears in a 1988 National Academy of Public Administration report entitled, "Effectiveness of NASA Headquarters", as follows: "We have. . . concluded that the term "operational" as applied to commercial aircraft, to ships, or to mass-produced articles of defense will most likely never apply to space systems in that same context. What we do see, however, are large, complex space systems such as the Shuttle and the Space Station that are or will be largely driven by operational issues — turnaround time between flights, manifesting, retrofitting of design changes for safety, cost or payload capability purposes, logistics, training of basic and science crew members, and so on. These are *not* the basic work of research and development leading to new concepts and ideas for future space systems, nor for expanding knowledge of the universe and discerning the implications of that knowledge for life on this planet or elsewhere." The report goes on to recommend an organizational separation, from the top of the agency down, on the two matters of space flight operations and space system development.

We endorse this approach, including the establishment of an Associate Administrator for Space Flight Operations. The responsibility of this individual should include Space Shuttle operations, ELV operations, and the Tracking and Data Systems organization. This Associate Administrator should have the institutional responsibility for injecting operational requirements into new programs to assure that they can be effectively operated over their lifetimes at reasonable cost. At the appropriate time, the responsibility for Space Station operations would also be assigned to this office. It is thus proposed—

That an Associate Administrator for Space Flight Operations be established whose responsibilities initially would include Space Shuttle operations, existing ELV operations, and tracking and data functions. Prior to implementing any such change, a detailed transition plan should be prepared and afforded full safety review and approval. (Item E.)

Current and possible headquarters organizational alignments are summarized in Figures 12 and 13.

Shuttle Operations. Management mechanisms now used to bring senior supervision and discipline to bear on Space Shuttle operations reflect the special emphasis that this has received in the last few years. Although occasional launch delays still occur, a process appears to be in place which surfaces concerns and resolves them. On the other hand, the Shuttle launch operation has evolved into a relatively slow and deliberate process, and we conclude that the laborious and labor intensive methods now employed may become a limiting factor in achieving the planned flight rates. Further, it is not likely that the Space Shuttle will ever emerge from the inherently expensive quasi-developmental stage unless responsibility is eventually moved from a development oriented center to the operationally oriented Kennedy Space Center (KSC). Such a move would

Figure 12

Nominal Current Headquarters Functional Organization

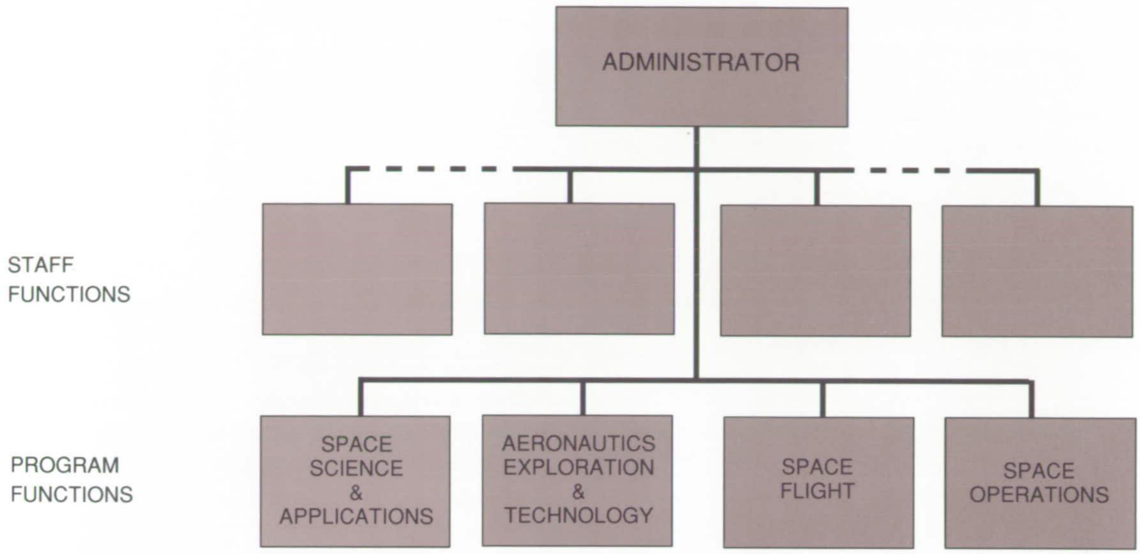
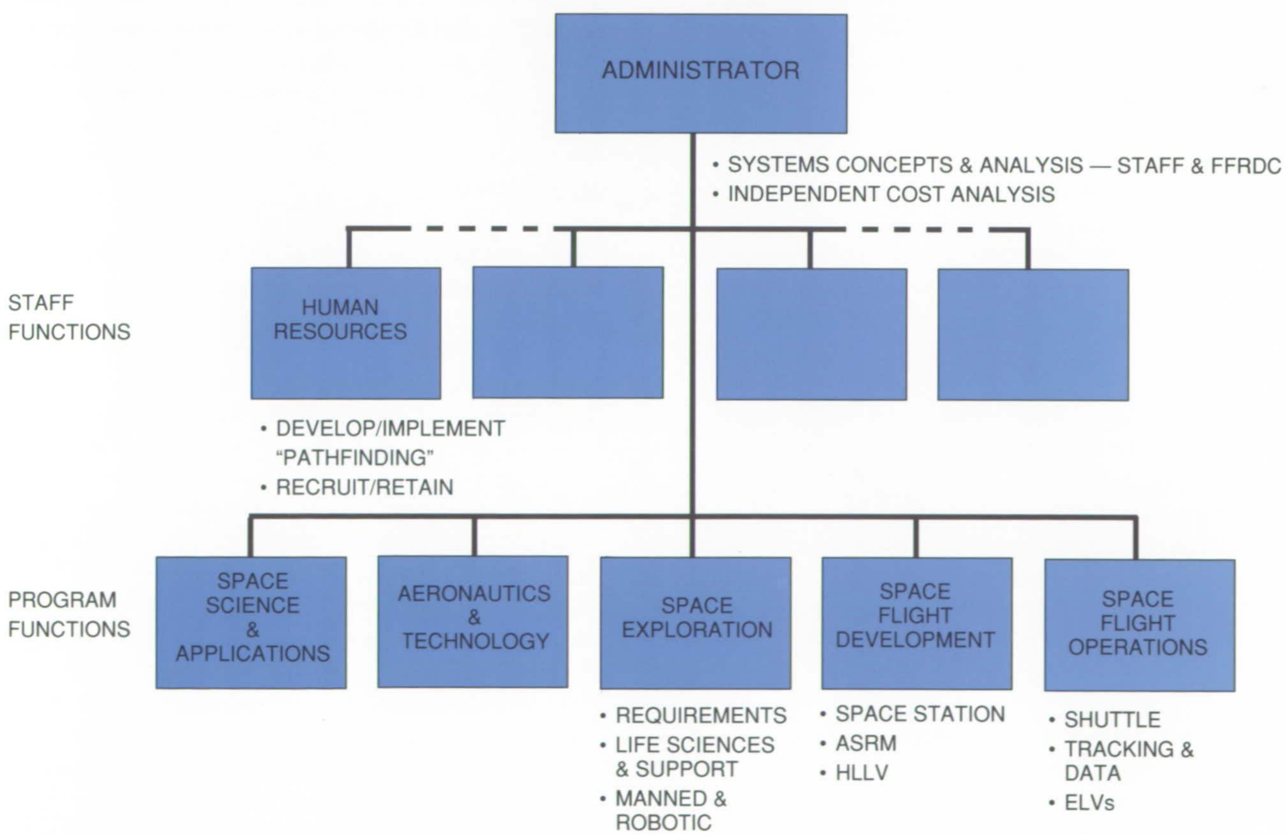


Figure 13

A Possible Nominal Headquarters Functional Organization



appear logical since maturation of Space Shuttle operations drives the focus of program activities toward KSC as flight rates increase. This transfer of support responsibility to KSC should include the concentration and centralization of as much of the program management from other locations as is feasible, including from headquarters.

Such a major move should be carefully implemented only when a reasonable and regular flight rate has been re-established, but the Committee is persuaded that now is the time to begin planning the process. The ultimate goal should be a safe operation, performed as efficiently and routinely as its complexity permits, and not burdened by excessive layers of management that are the legacy of the development era and recovery from the Challenger accident. Particular attention must be paid to management accountability at each stage of the transfer process. We conclude that —

NASA should begin the deliberate process of planning for the transition of the Space Shuttle from development to a more nearly operational status at Kennedy Space Center with continuing technical support from other centers, and with appropriate certification of safety considerations at each step of the transfer process. (Item F.)

Project Management. There is general agreement that projects should be assigned to, and largely performed by, a single center whenever possible. Nevertheless, there will always be some projects that demand assignment to more than one center because of the size of the projects and the necessity to draw on diverse expertise.

NASA has tried various approaches to this management challenge, ranging from headquarters project management to several forms of lead center arrangements. We submit, however, that *day-to-day* project management should not be performed from headquarters. It is not a natural function for any headquarters organization; people are not, and should not, be present within a headquarters in adequate numbers to staff such a function; the headquarters skill mix is inappropriate to project management; and the attempt to perform day-to-day project management undermines the critical oversight role that is a proper function of a headquarters staff.

Instead, we propose —

That NASA adopt as standard for the management of multi-center programs, a headquarters project manager and staff located at or near the "Primary Center" involved in the undertaking. A key attribute of such a project office would be its systems engineering capability. (Item G.)

This approach will preserve the integrity of the headquarters supervisory function while providing the project manager with the technical, administrative, and systems engineering support he or she will require.

Center Management. As NASA evolved during the decade of the 1960s, the missions of each center were relatively crisp and their respective capabilities developed into centers of excellence. To a large extent, these roles still exist and in many cases centers of excellence still prevail. But the focus has become somewhat blurred, for reasons that are generally well understood. With the phase-down following Apollo, several centers found their future prospects greatly diminished and sought additional work that could keep their talented staffs employed. As significant competence built up across centers in a variety of fields, diversification was sometimes even encouraged by headquarters program managers seeking competition between centers for new work.

The issue in this case is whether center responsibility overlap is appropriate in disciplines such as astrophysics, Earth sciences, microgravity and life sciences. The answer is no. Such diversification is inimical to a vigorous agency moving into new areas of space exploration. Each element of diversification requires additional (scarce) knowledgeable management, facilities and funding, and represents a corresponding diversion from the center's core mission. Hence —

***Recommendation 13 :* That NASA management review the mission of each center and consolidate and refocus centers of excellence in currently relevant fields of science and technology with minimum overlap between centers. An appropriate balance between in-house and external activity also should be developed.**

Internal/External Division of Labor. Over the years, NASA has developed a characteristic management style in the conduct of its research and development activities. Its approach was originally nurtured by the groups from which NASA was formed (primarily the NACA centers and Army space activities) and was institutionalized during NASA's first decade, when external space expertise hardly existed, and an aerospace industry had yet to be developed from airframe companies, their suppliers, and a nascent electronics industry. A supportive academic infrastructure also had yet to be generated. In this period, it was necessary for NASA to perform a great deal of work in-house, and to provide a substantial degree of oversight to the newly formed "space-industrial-academic complex."

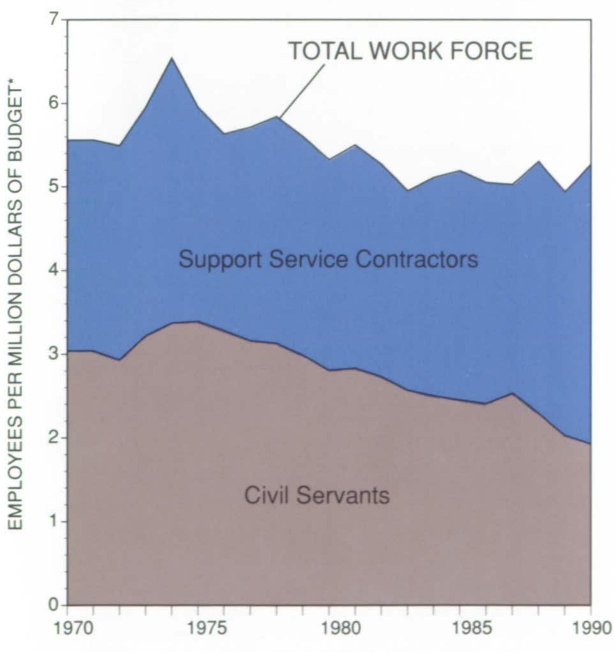
We believe that it is time to reconsider this management style, and to identify improvements that are relevant and necessary as the civil space program enters the next decade of research, development and exploration. Clearly, one very important advantage of NASA's approach is the existence of a staff with the ability to "buy smart" by virtue of hands-on experience. But the environment has changed. There is now a large and experienced space-academic community and an industrial base whose skills are broad and deep. The Department of Defense sponsored National Security Space Program is almost twice the size of NASA's program, but operates with only limited in-house laboratory support, and there is now an infant but developing commercial space industry.

NASA's civil service complement has remained relatively constant since the Apollo tail-off. On the other hand, in recent years this staff has been considerably augmented by the use of support service contractors (Figures 14 and 15). Issues that warrant consideration in this regard include: (1) What is an appropriate division of responsibilities between government and support contractor personnel?; and (2) Is such an organizational structure appropriate for NASA's emerging future responsibilities? Management's reassessment of this situation should recognize that some "hands-on" work must be retained as an important part of each center's responsibility. Legitimate functions include the mandate to push the frontiers of space science and technology continuously forward, as well as to train the future managers of large, complex space systems. But this should not be taken to mean that NASA must continue a substantial effort in every space-related field. Rather, NASA should focus its hands-on activities on the relevant emerging and strategic technologies, on tasks not able to be readily pursued elsewhere, and on the oversight of its contractors.

Turning to issues related to procurement, NASA, the national security organizations and various commercial entities all use different approaches to the conduct of this function. No single approach is correct for all situations. The Committee has noted, however, marked differences with respect to the staffing of the procurement operation within NASA. For instance, a typical national security space system will be managed by a program office of some 30 to 50 people augmented with either a Federally Funded Research and Development Center (FFRDC), a systems integration

Figure 14

NASA Work Force Trend
Employees in Relation to Budget

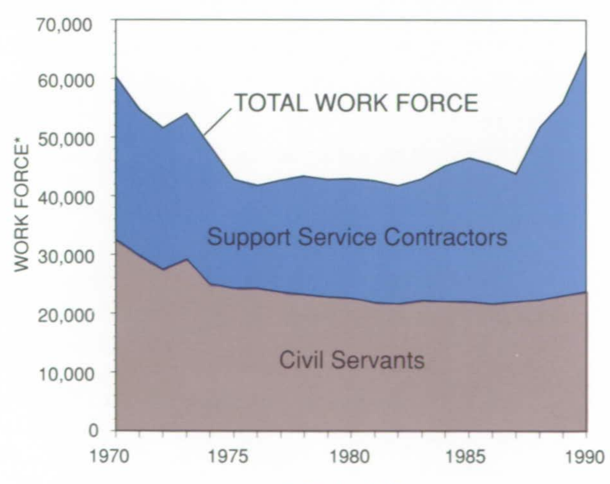


Source: NASA

*Full-Time Equivalents Budget in Constant 1990 Dollars
(Cost of Replacement Orbiter in 1987 omitted)

Figure 15

NASA Work Force Trend
(Number of Employees)



Source: NASA
*Full-Time Equivalents

contractor for technical and systems engineering support, or a prime contractor from industry. NASA, on the other hand, typically utilizes a corresponding program office which relies on center laboratories for technical support. In general, many more people are involved in NASA's approach, and certainly more government people. NASA technical staff members have remarked that contract oversight duties now consume a disproportionate amount of their time; time that they believe would be more beneficially devoted to hands-on work. Some centers address this concern by instituting a career branch point at which an experienced engineer or scientist can choose between remaining at the "bench," or becoming more involved with management. This approach helps assure a continuum of "smart buyers." However, we believe that —

NASA should concentrate its "hands-on" expertise in those areas unique to its mission, and avoid the excessive diversion of technical or mission specialists to functions which could be performed elsewhere. Contract monitoring is best accomplished by a cadre of professional systems managers with appropriate experience. Increased use of performance requirements, rather than design specifications, will further increase the effectiveness of this approach. (Item H.)

Procurement Policy. The critical issue of federal procurement policy has been addressed repeatedly by numerous panels and commissions for at least a quarter of a century. The Committee concludes that were the findings of these past reports to be implemented, a sufficient basis would be provided for improving the procurement system. Hence, no further detailed recommendations are made here.

Worthy of note, however, is the fact that since 1965, more than 60 new procurement-related public laws have been enacted. In addition, 25 Executive Orders, 16 Office of Management and Budget Circulars, and 24 Office of Federal Procurement Policy Letters have been issued, all of which affect the procurement process directly.

With few exceptions, none of these laws, orders or circulars distinguishes between the procurement of routine housekeeping or office supplies and state-of-the-art technology, hardware, or services. Although it was not within the scope of the Committee to judge the merits of these regulations, we were repeatedly advised that their cumulative effect was to lengthen, complicate and increase costs associated with the procurement process. We also noted numerous instances where direction, reports and limitations were included in annual authorization and appropriation acts that targeted the procurement and management processes. Each year such instructions add to the cumulative administrative and cost burdens. We conclude, therefore —

That the Legislative and Executive Branches should review the combined effect of current laws, executive orders and circulars on the efficiency of high-technology research and development operations. After review, pilot test acquisitions should be conducted with as many of the non-critical, procurement-related objectives removed as possible. The intent should be development of a more efficient process permitting both swift technical progress and sound business management. The results of the study and the pilot tests should be reported to the President and the Congress. Appropriate actions by the Legislative and Executive Branches should be recommended. (Item I.)

Commercial Programs. At the time of its formation in 1958, NASA was assigned responsibilities extending well beyond the conduct of individual space missions. These responsibilities included enhancing the technical competitiveness of the U.S. in space-related industries, and the transfer of space-derived technologies into all appropriate elements of American industry.

The direct application of space technology to the public good and to the economic benefit of the nation's industries began almost at the outset of the Space Age when Tiros I, the first weather satellite, and Echo I, the first communication satellite, were launched in 1960. The communication satellite industry rapidly became an important commercial commodity in the international marketplace.

Recognizing the growing importance of satellites and other possible commercial space products and services to the nation's competitive position, the Administration and the Congress expanded the scope of the Space Act in 1984 to require that NASA, together with its previously assigned duties regarding the development and transfer of space technologies, now additionally "seek and encourage to the maximum extent possible the fullest commercial use of space." The agency is thus charged with actively fostering a commercial space industry in much the same way as its predecessor NACA promoted (and NASA still promotes) the nation's broadly successful aviation industry. The Committee feels strongly the importance of the government's aggressively pursuing and meeting this responsibility to encourage space commercialization because:

- Domestic commercial space companies have grown to annual revenues exceeding $3.5 billion in just three decades; thus their products and services represent an increasingly important economic sector in the world marketplace;

- The U.S. cannot remain competitive in space technologies common to the world market unless private sector companies have and can sell high-technology products; correspondingly, only private capital can bring space technologies to bear on the national objective of improving the U.S. competitive position in the world trade; and
- Unlike the mature communications satellite industry, many areas of plausible space commercialization still are in their infancy, and thus will require additional support from the government before returns to the private sector can be reasonably expected.

The Committee observes that considerable effort has been undertaken within the National Space Council and across a multitude of government offices, committees and advisory groups to develop a comprehensive and implementable commercial space policy. Parts of such a policy already are in place as guidelines to supplement the broad commercial space charge given NASA in the revised Space Act. However, the federal government is still by far the major consumer of space products and services, and will continue to be a highly significant, if not dominant, consumer for many years to come.

Given the above, the Committee would emphasize the importance of the U.S. Government following as closely as practicable the model established by the NACA/NASA successes in the aeronautics industry in order to encourage the fullest commercial use of space. Examples wherein further government actions can be helpful include ensuring that procurements are based on "best value" rather than lowest cost; on the related experience and past performance of the contractor; on functional requirements, not on detailed design specifications; on accepting, whenever appropriate, commercial production and quality assurance standards and techniques; and on using commercially offered space products and services whenever possible. Of particular importance is that in its commercial contracting, the government recognize the need for credible long-term contracts. (Item J.)

Finally, the Committee notes that commercial space policies have undergone substantial change every two years since 1982, and even newer policies are currently being promulgated. Significant additional private investments are *not* likely to be made in commercial space ventures until these policies become stable, and are perceived by those making investment decisions as likely to remain stable.

International Programs. Various elements of the U.S. civil space program have for a number of years involved the participation of international partners. In the case of the science program, collaborative efforts have included instrument design and construction, the interpretation of data, and the provision of entire instruments by groups of interested individuals.

On a larger scale, international collaboration now involves teaming arrangements including international partnerships where portions of robotic spacecraft or even entire spacecraft, are involved. In the case of the manned space program, scientists from several nations participated in the design of some of the instruments placed on the Moon in the Apollo program. The Apollo/Soyuz linkage in space in 1975 was a high point for the U.S. in cooperative endeavors with another country, in this case, the Soviet Union. International participation in manned space flight activities has continued in the Space Shuttle era, involving the provision of hardware and flights of foreign astronauts.

In a 1988 report to the President-elect, the National Academies of Sciences and Engineering noted that "partnerships with other nations and organizations can serve to demonstrate leadership, to forge productive relationships and to broaden the range of available opportunities, but only if international commitments are made carefully and honored fully." This report further advised that when collaborative arrangements are contemplated, they be "supported at the highest possible levels in the participating governments, with as much breadth as is feasible."

We, too, would advise that, prior to entering into international arrangements, especially for the necessarily large human exploration program, the government first determine its own goals and expectations. Once undertaken, a commitment should become exactly that. Thus, it is probably not prudent, in a longer-term program such as human exploration of space, to establish international agreements for the development of in-line critical program elements. It would also probably not be prudent for the U.S. to establish international agreements for program elements that would result in the permanent loss of critical national technical capabilities. Nonetheless, we believe that international cooperation should and will become an increasingly important aspect of future space activities, particularly in support of such missions as environmental monitoring and weather prediction.

Personnel Resources

NASA today employs approximately 24,000 civil servants, and has grown only modestly over the past five years. NASA's government employees are supported by some 41,000 support services contractors, and their numbers have grown substantially in the past three years.

For the nation to undertake the challenging and aggressive space program set forth by the President, it will require NASA and its supporting organizational elements to recruit and retain an adequate share of the nation's very best technical and managerial talent. In the past, the Apollo and early Space Shuttle pursuits offered the excitement needed to attract many such individuals. As we look to the future, however, the Committee is deeply concerned over NASA's ability to continue to attract such people. There are several reasons for this situation.

First, the restrictions of the civil service compensation system are not likely to permit NASA to be competitive with the private sector in recruiting and retaining the highest quality personnel in the decade ahead. As a specific example, since the beginning of the program in August 1984, there have been five different Associate Administrators for Space Station and five different Space Station Program Directors. Current civil service regulations on base pay, pay raise schedules, relocation costs, bonus opportunities and "dual compensation" all constrain NASA's ability to compete for talent.

In the case of new college graduates, private industry is able to pay some $5,000 to $10,000 more per year than is NASA, especially in high cost-of-living areas — and that gap has been widening. The problem is particularly acute in the science and engineering disciplines where the number of college graduates is expected to decline by some 25 percent over the next decade.

A 1989 study of the Bureau of Labor Statistics indicated that federal employee salaries were, on average, 28.6 percent below those of the private sector. In an unpublished NASA study of compensation, it was shown that the Director of a major NASA center was paid about one-half as much as a person with equivalent responsibilities in industry. At higher levels the disparity is even greater.

Second, recent post-employment restrictions on individuals — and particularly the future uncertainty of those restrictions and their interpretation — have been a deterrent to the recruitment of talented technical and managerial personnel into NASA. Key managers with extensive industrial experience in technical programs are particularly reluctant to commit to government service in areas where their talent could be effectively and immediately utilized — again because of concern over post-government employment restrictions. These restrictions were, of course, imposed to preclude possible conflicts of interest, but have been found extremely difficult to draft with precision and balance. Last year, five individuals from industry were approached concerning one key executive level position at NASA. All declined, primarily because of inadequate compensation and post-employment restrictions. A similar effect has been noted in recent cases where extraordinarily talented NASA employees have elected to terminate their government service.

These two problems will be *partially* offset in the future if the Executive and Legislative Branches are perceived to have jointly committed to an ambitious and challenging long-term space program. But it is our opinion that, although absolutely essential, such a program alone is not enough to attract and keep the talent needed. In fact, with the declining pool of available technical talent and the expanding gap between federal and private salaries, it is not at all clear that NASA will be able to meet the future challenges of an ambitious space program unless deliberate actions are taken now to redress the situation.

We have been somewhat encouraged by the recent passage of legislation increasing Executive and Senior Executive Service pay levels, and by the passage of the Federal Employees Pay Comparability Act of 1990, effecting a degree of long overdue reform of the civil service salary system. Once fully implemented by the Office of Personnel Management (OPM), pay reform will provide base pay increases and compensation adjustments based on local labor costs, as well as other incentives such as recruitment and relocation bonuses and retention allowances. But this positive action may still not be sufficient to remedy a situation of the severity that now prevails.

The difficulty of removing civil servants who are not performing up-to-standard work creates even more acute problems for NASA. Its inability to easily and quickly remove non-performers further limits its ability to recruit new talent to meet future challenges. NASA management needs the additional flexibility to reward high-performers and remove non-performers swiftly. Accordingly, we propose —

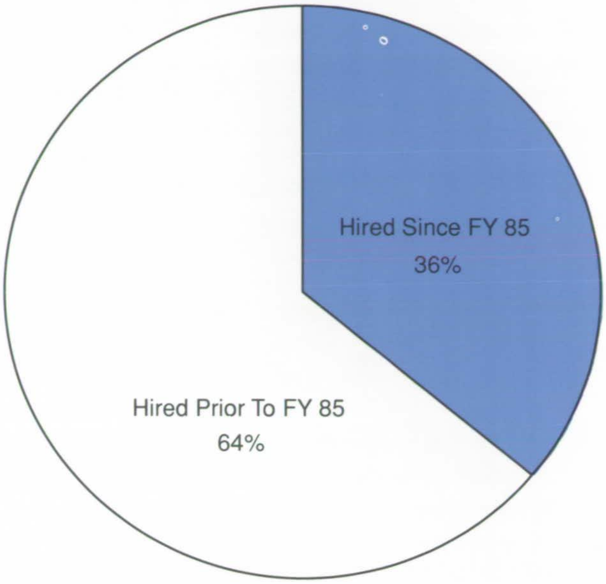
Recommendation 14: **That NASA should be designated a "pathfinding" agency for the implementation of an advanced personnel management system. Under this system the**

current legislative package would be expanded to include "pay for performance;" more flexibility in senior executive hiring, evaluation and removal; additional cost reimbursement for relocation; and a capability for handling extended temporary duty costs. NASA management should propose to OPM the personnel package it deems appropriate in the above regards.

Another human resources concern relates to the expected future reduction of experienced managerial talent at NASA. Today, a very large number of personnel are relatively new to the agency (Figure 16). This is illustrated by the "bimodal" age distribution of NASA employees (Figure 17). Within the past ten years the distribution of age and experience at NASA has moved from a maximum share appearing within the age brackets of 35 to 50 years to maximum occurring at 25-29 years and 45-54 years. While it is encouraging that the average age of NASA employees is decreasing, it is of concern to the Committee that the pool of talent in the 35-49 year bracket, from which future senior managers are usually drawn, is decreasing significantly.

Figure 16

NASA's Changing Workforce

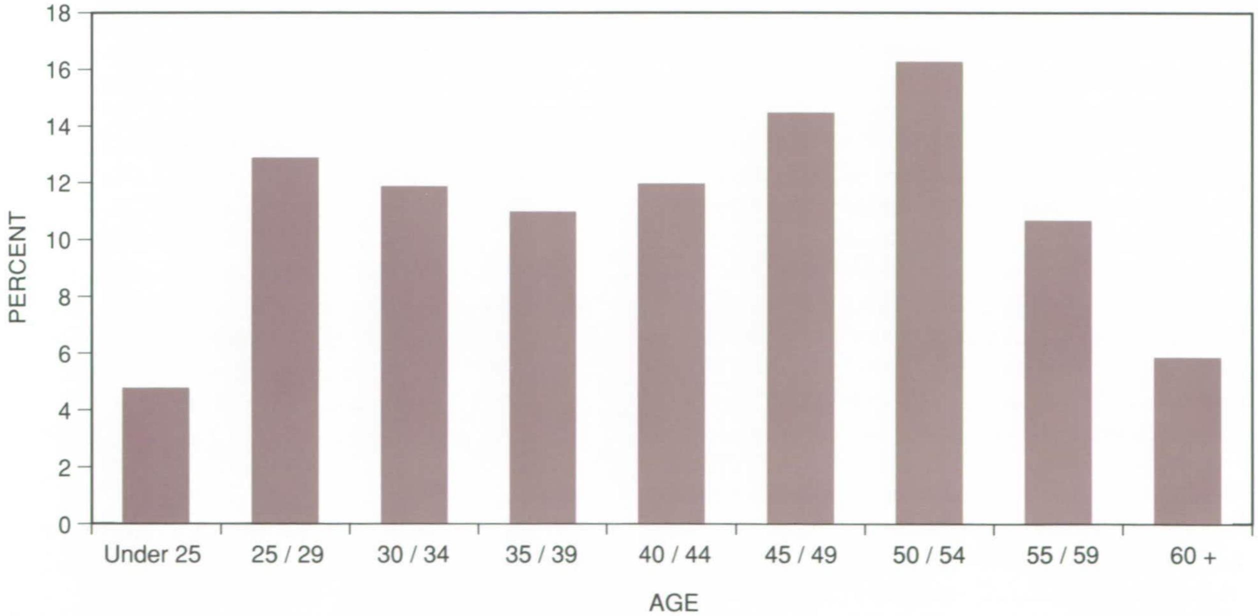


Over a Third of Today's Workplace Hired in Past 6 Years

Source: NASA

Figure 17

Age Profile of Permanent Employees



Source: NASA

Based on historical attrition rates, NASA will lose over half of its senior-level managers in the next 5 to 10 years. Not only must the Executive and Legislative Branches address the total compensation system to recruit and retain talent to fill these and other key positions, it must also ensure that adequate resources are provided for career development of individuals already within NASA, not only to increase the size of the talent pool, but also to grow the capabilities of persons in the pool so that they may compete most effectively for increased responsibilities.

The Space Act of 1958 provided NASA with flexibility to hire up to 425 "critical-position" personnel, but NASA has not in recent years fully utilized this flexibility. The Office of Personnel Management also has the authority to allocate an additional 800 "critical-skills" personnel to various government agencies, and NASA should ensure that it receives an appropriate share of these positions. In addition, OPM has recently increased NASA's authority to hire special non-manager "Scientific and Technical" personnel at more competitive salaries. These all are steps in the right direction — although impacting only a small fraction of NASA's work force.

A further possibility arises from consideration of the arrangement between NASA and the California Institute of Technology for management of the Jet Propulsion Laboratory. In the Committee's opinion, this has provided an enormously effective means of obtaining needed technical expertise unfettered by the adverse civil service restrictions. It is a model that could have wider application as the U.S. space program expands, although its broader use requires very careful planning in the transition process.

Such possibilities lead to —

Recommendation 15: **That the Office of Personnel Management provide NASA the full flexibility permitted by law regarding dual compensation waivers, and that OMB allocate to NASA a significant portion of the 800 now approved "world-class" positions. NASA also should fully utilize the authority granted by the Space Act and fill all 425 "critical" personnel positions, thus helping redress locality pay inequities that will not be alleviated quickly enough by pay reform. New legislation should authorize NASA broad authority to establish, set the pay of, and fill up to 10 percent of its positions with "critical skills" appointments. In the event that recent and planned civil service reforms do not promptly alleviate the shortcomings of the NASA personnel system then, NASA should initiate the process of selectively phasing additional centers into the Jet Propulsion Laboratory model; that is, affiliate them with a university as Federally Funded Research and Development Centers.**

The ability to recruit and retain an adequate share of the nation's best technical and managerial talent will determine to a great extent NASA's ability to carry out the ambitious civil space program herein envisioned over the next thirty years. For this reason, the Committee believes it is extremely important that NASA management place very high priority on personnel resources, including innovative solutions to the impediments of personnel recruitment, retention, training, replacement, and rewarding. To this end, it will be very important for NASA management to work closely with the OPM, the OMB, and the responsible Congressional Committees to develop flexible personnel regulations and to request appropriate reform measures. The Committee proposes, therefore —

That an Associate Administrator for Human Resources be established at NASA headquarters who shall be responsible for the recruitment to NASA of persons with critical skills, for ensuring that NASA maintain competitive compensation and personnel development policies to retain such people, and for working with OPM, OMB and the Congress on additional reforms to remove impediments to the recruitment and retention of talented and motivated people. (Item K.)

The Committee notes that current statistics on technical and scientific education within this country reveal that U.S. high school students are taking fewer science and mathematics courses than their peers in any advanced nation in the world. Further, the number of U.S. college graduates pursuing careers in science and engineering has decreased by nearly 50 percent over the past 30 years. Because NASA must draw heavily upon the engineering talents available in the U.S., we applaud NASA's active role in helping reverse these trends and encourage its continued effort in this regard.

Principal Recommendations

This report offers specific recommendations pertaining to civil space goals and program content as well as suggestions relating to internal NASA management. These are summarized below in four primary groupings. In order to fully implement these recommendations and suggestions, the support of both the Executive Branch and Legislative Branch will be needed, and of NASA itself.

Principal Recommendations Concerning Space Goals

It is recommended that the United States' future civil space program consist of a balanced set of five principal elements:

- a science program, which enjoys highest priority within the civil space program, and is maintained at or above the current fraction of the NASA budget (Recommendations 1 and 2);
- a Mission to Planet Earth (MTPE) focusing on environmental measurements (Recommendation 3);
- a Mission from Planet Earth (MFPE), with the long-term goal of human exploration of Mars, preceded by a modified Space Station which emphasizes life sciences, an exploration base on the Moon, and robotic precursors to Mars (Recommendations 4, 5, 6, and 7);
- a significantly expanded technology development activity, closely coupled to space mission objectives, with particular attention devoted to engines (Recommendation 8);
- a robust space transportation system (Recommendation 9).

Principal Recommendations Concerning Programs

With regard to program content, it is recommended that:

- the strategic plan for science currently under consideration be implemented (Recommendation 2);
- a revitalized technology plan be prepared with strong input from the mission offices, and that it be funded (Recommendation 8);
- Space Shuttle missions be phased over to a new unmanned (heavy lift) launch vehicle except for missions where human involvement is essential or other critical national needs dictate (Recommendation 9);
- Space Station Freedom be revamped to emphasize life sciences and human space operations, and include microgravity research as appropriate. It should be reconfigured to reduce cost and complexity; and the current 90-day time limit on redesign should be extended if a thorough reassessment is not possible in that period (Recommendation 6);
- a personnel module be provided, as planned, for emergency return from Space Station Freedom, and that initial provisions be made for two-way missions in the event of unavailability of the Space Shuttle (Recommendation 11).

Principal Recommendations Concerning Affordability

It is recommended that the NASA program be structured in scope so as not to exceed a funding profile containing approximately 10 percent real growth per year throughout the remainder of the decade and then remaining at that level, including but not limited to the following actions:

- redesign and reschedule the Space Station Freedom to reduce cost and complexity (Recommendation 6);
- defer or eliminate the planned purchase of another orbiter (Recommendation 10);
- place the Mission from Planet Earth on a "go-as-you-pay" basis, i.e., tailoring the schedule to match the availability of funds (Recommendation 5).

Principal Recommendations Concerning Management

With regard to management of the civil space program, it is recommended that:

- an Executive Committee of the Space Council be established which includes the Administrator of NASA (Recommendation 12);
- major reforms be made in the civil service regulations as they apply to specialty skills; or, if that is not possible, exemptions be granted to NASA for at least 10 percent of its employees to operate under a tailored personnel system; or, as a final

alternative, that NASA begin selectively converting at least some of its centers into university-affiliated Federally Funded Research and Development Centers (Recommendations 14 and 15);
- NASA management review the mission of each center to consolidate and refocus centers of excellence in currently relevant fields with minimum overlap among centers (Recommendation 13).

It is considered by the Committee that the *internal* organization of any institution should be the province of, and at the discretion of, those bearing ultimate responsibility for the performance of that institution. Hence, the following possible internal structural changes are offered for the consideration of the NASA Administrator:
- That the current headquarters structure be revamped, disestablishing the positions of certain existing Associate Administrators in order that:
  - an Associate Administrator for Human Resources be established, whose responsibilities include making NASA a "pathfinding" agency in acquisition and retention of the highest quality personnel for the Federal Government (Item K);
  - an Associate Administrator for Exploration be established, whose responsibilities include robotic and manned exploration of the Moon and Mars (Item C);
  - an Associate Administrator for Space Flight Operations be established, whose responsibilities include Space Shuttle operations, existing expendable launch vehicle operations, and tracking and data functions (Item E);
  - an Associate Administrator for Space Flight Development be established, whose responsibilities include Space Station Freedom and other development projects such as the Advanced Solid Rocket Motor and the new Heavy Lift Launch Vehicle (Item D);
- an exceptionally well-qualified independent cost analysis group be attached to headquarters with ultimate responsibility for all top-level cost estimating including cost estimates provided outside of NASA (Item B);
- a systems concept and analysis group reporting to the Administrator of NASA be established as a Federally Funded Research and Development Center (Item A);
- multi-center projects be avoided wherever possible, but when this is not practical, a strong and independent project office reporting to headquarters be established near the center having the principal share of the work for that project; and that this project office have a systems engineering staff and full budget authority (ideally industrial funding,— i.e., funding allocations related specifically to end goals) (Item G).

In summary, we recommend:
1) Establishing the science program as the highest priority element of the civil space program, to be maintained at or above the current fraction of the budget.
2) Obtaining exclusions for a portion of NASA's employees from existing civil service rules or, failing that, beginning a gradual conversion of selected centers to Federally Funded Research and Development Centers affiliated with universities, using as a model the Jet Propulsion Laboratory.
3) Redesigning the Space Station Freedom to lessen complexity and reduce cost, taking whatever time may be required to do this thoroughly and innovatively.
4) Pursuing a Mission *from* Planet Earth as a complement to the Mission *to* Planet Earth, with the former having Mars as its very long-term goal — but relieved of schedule pressures and progressing according to the availability of funding.
5) Reducing our dependence on the Space Shuttle by phasing over to a new unmanned heavy lift launch vehicle for all but missions requiring human presence.

* * *

The Committee would be pleased to meet again in perhaps six months should the NASA Administrator so desire, in order to assist in the implementation process. In the meantime, NASA may wish to seek the assistance of its regular outside advisory group, the NASA Advisory Council, to provide independent and ongoing advice for implementing these findings.

Each of the recommendations herein is supported unanimously by the members of the Advisory Committee on the Future of the U.S. Space Program (see Appendix III).

Appendices

I. Biographies of Members
II. Terms of Reference
III. Legal Compliance
IV. List of Witnesses
V. Bibliography

Appendix I
Biographies of Members

Chairman:

Norman R. Augustine Mr. Augustine is Chairman and CEO of the Martin Marietta Corporation. He has previously served as the Under Secretary of the Army, Assistant Secretary of the Army for Research and Development and as an Assistant Director of Defense Research and Engineering in the Office of the Secretary of Defense. He is an Honorary Fellow and former President of the American Institute of Aeronautics and Astronautics and is a Fellow of the Institute for Electrical and Electronic Engineers. He has served as Chairman of the Defense Science Board and of the Aeronautics Panel of the Air Force Scientific Advisory Board. He is the author of several books including one on the management of large technical projects and is a member of the National Academy of Engineering. He currently serves as Vice President of the Boy Scouts of America. Mr. Augustine holds Bachelors and Masters degrees in aeronautical engineering from Princeton University and has three honorary doctorate degrees.

Vice-Chairman:

Laurel L. Wilkening Dr. Wilkening is the Provost and Vice President for Academic Affairs of the University of Washington, where she is also Professor of Geological Sciences and Adjunct Professor of Astronomy. Prior to going to the University of Washington, she was Vice President for Research and Dean of the Graduate College and Professor of Planetary Sciences at the University of Arizona. She also served as Director of the Lunar and Planetary Laboratory there from 1981-1983. As a planetary scientist, her areas of research are meteorites, asteroids, and comets. The book *Comets,* which she edited in 1982, is a widely used reference on the topic. In 1985, President Reagan appointed her Vice Chairman of the National Commission on Space. Dr. Wilkening earned a Ph.D. in chemistry from the University of California, San Diego in 1970, and a B.A. in chemistry from Reed College, Portland, Oregon in 1966.

Members:

Edward C. "Pete" Aldridge, Jr. Mr. Aldridge is currently President, McDonnell Douglas Electronic Systems Company, in McLean, Virginia. Prior to this position, Mr. Aldridge was Secretary of the Air Force from 1986-1988. He joined the Reagan Administration in 1981 as the Under Secretary of the Air Force, in which one of his key responsibilities was coordinating the Air Force and national security space activities. Mr. Aldridge was in astronaut training before the Challenger accident. He has held numerous management positions in government (Office of the Secretary of Defense, Office of Management and Budget) and the aerospace industry (System Planning Corporation, LTV Corp and Douglas Aircraft Co.). Mr. Aldridge was an advisor on the Strategic Arms Limitation Talks (SALT I) in 1970-72. He holds a B.S. in Aeronautical Engineering from Texas A&M University and an M.S. in aeronautical engineering from the Georgia Institute of Technology.

Joseph P. Allen Dr. Allen is currently President, Space Industries, Inc., in Houston, Texas. From 1967 until his employment with the company, Dr. Allen served as an astronaut with NASA. His management duties involved astronaut candidate selection and training and he additionally served as a ground support crewman and CAPCOM for Apollo 15, Apollo 17 and STS-1. He flew as a prime crew member on STS-5, the first Shuttle flight to deploy cargo in space, and on STS 51-A, the first space flight to salvage equipment from space. Dr. Allen also served at NASA Headquarters as Assistant Administrator for Legislative Affairs from 1975-1978. He is the author of *Entering Space*, a personal account of the space flight experience, and has published widely in the fields of science education and nuclear physics research. Dr. Allen received an undergraduate degree in mathematics and physics from DePauw University and holds Masters and Doctorate degrees in physics from Yale University.

D. James Baker Dr. Baker is President of Joint Oceanographic Institutions, Inc. in Washington, D.C., and Distinguished Visiting Scientist at the Jet Propulsion Laboratory. He is author of *Planet Earth - The View from Space* (Harvard University, 1990). He is a member of the National Research Council Committee on Global Change and the Ocean Studies Board, and is an officer of the international Joint Scientific Committee for the World Climate Research Programme. He has served as Chairman of the NRC Panel to Review the Earth Observing System and Chairman of the NASA

Center Science Assessment Team. He has served as a member of the NRC Space Studies Board, the NASA Space and Earth Science Advisory Committee, and the Department of Commerce Committee on Commercialization of Landsat. He is President of the Oceanography Society and a Fellow of the American Association for the Advancement of Science. Dr. Baker has published more than 80 papers on oceanography and space and held positions at the University of Washington and Harvard University. He has a B.S. in physics from Stanford University and a Ph.D. in physics from Cornell University.

Edward P. Boland Congressman Boland was elected to the U. S. House of Representatives in 1953 and served continuously through the end of the 100th Congress in 1988. In 1955, he joined the Committee on Appropriations and was a member of the Independent Offices (now the VA, HUD, and Independent Agencies) Subcommittee. In 1971, he became Chairman of this subcommittee and dealt with several scientific agencies including the National Aeronautics and Space Administration (formerly the National Advisory Committee on Aeronautics), the National Science Foundation, and the Office of Science and Technology Policy. He also served as Chairman of the first House Permanent Select Committee on Intelligence overseeing the budgets of the Central Intelligence Agency, and other intelligence related agencies. In 1983, Congressman Boland received the Olin E. Teague Space Award in recognition of his outstanding guidance and dynamic leadership in space science. In 1986, he received the National Science Foundation Distinguished Public Service Award presented in recognition of his contribution to the progress of science, engineering, and mathematics. He attended Boston College Law School.

Daniel J. Fink Mr. Fink is President of D. J. Fink Associates, Inc., which provides management consulting to technology based industries. His over 40 years in aerospace engineering and management include service in the DOD as Deputy Director, Strategic & Space Systems. Following his government service he joined the General Electric Company in 1968. He was Vice President of that company where he first led GE's Space Division, then its Aerospace Group, and later was Senior Vice President Corporate Development and Planning. Mr. Fink serves on the Defense Science Board and is a former Chairman of the NASA Advisory Council. He is a Member of the National Academy of Engineering and was Chairman of the NRC Space Applications board and its Board on Telecommunications and Computer Applications. His honors and awards include the DOD Distinguished Service Award, the NASA Distinguished Public Service Medal and the Collier Trophy (for his work on Landsat). He is an Honorary Fellow of the American Institute of Aeronautics & Astronautics and a former President. He received his B.S. and M.S. in aeronautical engineering from Massachusetts Institute of Technology

Don Fuqua Mr. Fuqua is President and General Manager of the Aerospace Industries Association and serves as leading spokesperson for the U.S. aerospace industry. Before joining AIA, Mr. Fuqua served 12 terms as a U.S. Congressman, representing Florida's Second Congressional District. He was elected Chairman of the House Science and Technology Committee in 1979 after serving on the Committee since joining Congress in 1963. He is a member of the National Aeronautics and Space Administration's Advisory Council and is a founding member of the Challenger Center for Space Science Education. Mr. Fuqua has received numerous awards including the Rotary National Award for Space Achievement in 1988, and the National Aeronautics and Space Administration Distinguished Public Service Medal and the National Science Foundation Distinguished Public Service Award, both in 1986. Mr. Fuqua graduated from the University of Florida with a degree in agriculture economics. He also has honorary doctorate degrees from the University of Notre Dame, Florida Institute of Technology, Florida State University, and Florida A&M University.

Robert T. Herres General Herres retired in March 1990 after 36 years of military service to become President of Property and Casualty Insurance Division at USAA, an insurance and financial services provider. The last three years of his military career were spent as Vice Chairman of the Joint Chiefs of Staff. Space related assignments included service as Commander-in-Chief of U.S. Space Command, North American Aerospace Defense Command, and Commander of the Air Force Space Command. He was also Director of Command, Control and Communications Systems on the Joint Staff, Commanded the Eighth Air Force and the Air Force Communications Command. Earlier, General Herres was the Air Force Flight Test Center's Chief of Plans and Requirements and Chief of the Flight Crew Division for the Manned Orbiting Laboratory Program subsequent to completing the Air Force's

Test Pilot School. He is a Naval Academy graduate and holds Masters' Degrees in electrical engineering and public administration.

David T. Kearns Mr. Kearns is Chairman of Xerox Corporation, Stamford, Connecticut. Mr. Kearns joined Xerox in July 1971 as a corporate vice president. In 1972, he became President of the Company's copier/duplicator group. He was named Executive Vice President, International Operations in 1976. He was named President and Chief Operating Officer in 1977 and Chief Executive Officer in 1982. Mr. Kearns served as Chief Executive Officer until he relinquished that position in August 1990. Prior to joining Xerox, Kearns was a Vice President of the data processing division of International Business Machines Corporation. Mr. Kearns is a member of the President's Education Policy Advisory Committee, the Business Council, the Council on Foreign Relation, the Trilateral Commission and the American Philosophical Society. He is a member of the Board of Directors of Chase Manhattan Corporation, Time Warner, Inc., Ryder System, Inc., and the Dayton Hudson Corporation. He also serves as a member of the Board of Trustees of the Ford Foundation, the National Urban League and the University of Rochester. He served in the United States Navy, and he graduated from the University of Rochester in 1952 with a degree in business administration.

Louis J. Lanzerotti Dr. Lanzerotti, Distinguished Member of the Technical Staff, AT&T Bell Laboratories, and Adjunct Professor of Electrical Engineering at the University of Florida, has also served as Regents' Lecturer at UCLA. His principal research interests include space plasmas, geophysics, and engineering problems related to the impact of space processes on space and terrestrial technologies. He is a co-investigator and principal investigator on NASA missions, and conducts extensive ground-based and laboratory research on space related topics. He was Chairman of NASA's Space and Earth Science Advisory Committee and is presently Chairman of the Space Studies Board of the National Research Council. Elected to the National Academy of Engineering and the International Academy of Astronautics, he is also a Fellow of the American Geophysical Union, the American Physical Society, and the American Association for the Advancement of Science. Dr. Lanzerotti has received NASA's Distinguished Public Service Medal. He has an engineering degree from the University of Illinois and M.A. and Ph.D. degrees in physics from Harvard.

Thomas O. Paine Dr. Paine is Chairman of Thomas Paine Associates, a member of the National Academy of Engineering, and a Director of the Planetary Society, the National Space Institute, the International Academy of Astronautics, Orbital Sciences Corporation, the Pacific Forum, Quotron Systems (Division of Citicorp), and Nike, Inc. He joined the General Electric Research Laboratory in 1949, and in 25 years with GE served as Manager of GE's TEMPO (long-range technoeconomic studies), Vice President and Group Executive of the Power Generation Group (worldwide ship propulsion, nuclear power and steam and gas turbine-generators), and Senior Vice President for Science and Technology (oversight of GE's research and development). During the first seven Apollo missions from 1968 through 1970, he was Administrator of NASA. From 1976 to 1982, he was President, Chief Operating Officer and Director of Northrop Corporation. Dr. Paine also has served as a Trustee of Occidental College and Brown University, and a Director of Eastern Air Lines, Arthur D. Little, RCA, and NBC. In 1985, President Reagan appointed him Chairman of the National Commission on Space, a panel created by the Congress to chart civilian space goals for 21st Century America. He received a Ph.D. in physical metallurgy from Stanford University in 1949.

Committee Support:

James D. Bain, Committee Executive Secretary
James R. Beale, National Space Council Staff Liaison
Darrell R. Branscome, Technical
Laura J. Cooper, Administrative
Edward A. Frankle, Committee Counsel and Ex-Officio Committee Member
Frances L. Gragg, Technical and Administrative
Lauren B. Leveton, Technical and Administrative
Dolores L. McClung, Administrative
John E. O'Brien, Ex-Officio Committee Member
George Reese, Committee Counsel
M. Ruth Rosario, Administrative
Albert R. C. Westwood, Committee Consultant
Yvonne Williams, Administrative

Appendix II
Terms of Reference

Advisory Committee on the Future U.S. Space Program

Purpose
The purpose of the Advisory Committee on the Future of the U.S. Space Program is to advise the NASA Administrator on overall approaches NASA management can use to implement the U. S. Space Program for the coming decades.

Task Statement
The Committee shall have a broad charter to:

- Review the future of the civil space program, including both management issues and program content.
- Assess alternative approaches and make recommendations for implementing future civil space goals, including such factors as:
  - Appropriateness of planned activities
  - Organizational balance and structure
  - Adequacy of overall skill base of work force
  - Balance between roles of government and private sector
  - Possible contributions by other government agencies
  - The need to maintain a strong R&D capability
  - Assurance of mission success

Schedule
The Committee shall report its findings within 120 days from the date of its inception.

Membership
The Committee shall be comprised of approximately 12 individuals selected for their knowledge of space activities and management expertise. Membership shall provide as broad a set of experience backgrounds as practicable. Ex-officio members may be added to the Committee upon approval of the Administrator of NASA with the concurrence of the Committee's Chairman

Reporting Procedure
The Committee will operate as an independent entity, reporting to the Administrator of NASA, and will submit its findings to the Administrator of NASA and, with the Administrator, to the Vice President of the United States, in his capacity as Chairman of the National Space Council.

Support
Administrative support will be provided to the Committee by NASA.

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

Appendix III
Legal Compliance

Some members of the Committee, through their private employment, have interests in the aerospace community and, consequently, the activities of NASA. This factor was taken into serious consideration when they were appointed to the Committee and, pursuant to applicable laws, it was determined that the need for the individuals' services outweighed the potential for a conflict of interest. It was the further determination of the appointing authority that the private interests of the individuals appointed to the Committee were not so paramount as to impede their objectivity or integrity as members of the Committee. These determinations were made by the appointing authority only after coordinating with the Office of Government Ethics to ensure full compliance with existing laws and regulations regarding the avoidance of conflicts of interest. A government attorney sat in on all sessions of the Committee at the request of the Committee Chairman.

In addition, the members of the Committee, recognizing there was an important concern as to avoiding even the mere appearance of a conflict of interest, endeavored throughout their Committee activities to minimize, wherever possible, any such possible appearance.

In this regard, because of his role as Chairman of the Committee and his position as a senior executive with an aerospace company, the Chairman of the Committee elected to disqualify himself from any decisions as to whether and how the Committee would address the issue of a new launch system. The deliberations and decisions as to this matter were handled by the Vice Chairman.

Appendix IV Witnesses

(Individuals Appearing Before Advisory Committee on the Future of the U. S. Space Program and its Working Groups)

John Aaron
George Abbey
James A. Abrahamson
Brant Adams
Larry Adams
Clyde Albertgottie
Mark Albrecht
Arnold D. Aldrich
Buzz Aldrin
Ron Alexander
LaTonya Alexander
Lew Allen
Harold Ammond
Sam Araki
Hugh Arif
Sam Armstrong
Jack Arrison
F. Ron Bailey
Randy Baggett
Brad Baker
William F. Ballhaus
Peter M. Banks
Richard W. Barnwell
David Barrett
Reginald Bartholomew
James E. Bartlett
Jeffrey E. Bauer
Robert C. Baumann
Brian Beckman
James Beggs
Joyce Bergstrom
William E. Berry
Mark Bethea
Vincent J. Bilardo
Nancy F. Bingham
David Black
Erich Bloch
Charles Bofferding
Albert Boggess
Daniel Boorstin
Carl O. Bostrom
Roland L. Bowles
Jeffrey S. Brady
Peter Bracken
Howard Branch
David Brannon
Porter Bridwell
Robert C. Bruce
James O. Bryant
Richard Bunevitch
Bonnie Buratti
Linwood G. Burcher
Peter T. Burr
Antonio Busalacchi
Lucinda Byrne
Gregory H. Canavan
Sandra Cargill
John Casani
Gerhard Casper
Frank J. Cepollina
Norm Chaffee
Moustafa Chahine
Elaine L. Chao
Charles R. Chappell
Michael Chilicki
Ronald Chinnapongse
A. Chutjian
Harlan Cleveland
Thomas Cochran
Aaron Cohen
Ray S. Colloday
James E. Colvard
Michael Comberiate
Dale L. Compton
Davis S. Coombs
Robert S. Cooper
John J. Cox
Harry Craft
Donald Cromer
Ray Cronise
A. P. Croonquist
Philip E. Culbertson
Frank Curran
Richard Darman
Charles R. Darwin
C. Calvin Davis
Rick Davis
Kirk Dawson
Clyde Dease
Hugh Dilion
Duane Dipprey
Peter Doms
Martin J. Donohoe
Regina Dorsey
Jeffrey C. Dozier
Robert E. Eddy
Charles Elachi
Donald Engen
George English
Roy S. Estess
Thomas Everhart
Maxime Faget
Dale L. Fahnestock
David T. Fahringer
Christine M. Falsetti
James W. Fenbert
Harry B. Finger
Lennard A. Fisk
George Fleming
James C. Fletcher
Charles T. Force
Stuart Fordyce
David Francisco
Rosemary C. Froehlich
Robert Frosch
Cynthia Fry
Michael Fry
Robert Frye
L. L. Fu
Ann Fulton
Randy Furnas
Daryal Gant
Lori Garver
Steven W. Gayle
Riccardo Giacconi
Dawn Gifford
Stan Gill
Otto K. Goetz
William Goldsby
Robert E. Grady
Daniel Gregory
Jerry Grey
Angelo "Gus" Gustaferro
Denton Hanford
Peggy W. Harmon
Roy V. Harris
Steven A. Hawley
Norman Haynes
Donald P. Hearth
Buzz Hello
Arthur Henderson
Francisco J. Hernandez

Noel Hinners
Wendy Holladay
Harry C. Holloway
Paul F. Holloway
Richard B. Holt
Stephen S. Holt
Jay Honeycutt
Ralph M. Hoodless
W. Ray Hook
Thomas J. Horvath
Thomas R. Huber
Kenneth R. Human
Carolyn L. Huntoon
Dale Hupp
William F. Huseonica
Jeffery C. Hyle
Rene Ingersoll
Thomas Irvine
Martin H. Israel
Roger L. Jenkin
Linda M. Jensen
Michael Johnson
Stephen Jung
Said Kaki
Samuel W. Keller
Cynthia Kelly
Regina Kelly
Eugene L. Kelsey
Satish Khanna
George H. Kidwell
Jenny S. Kishiyama
Ray Kline
John M. Klineberg
Martin A. Knutson
Chester Koblinsky
John Koudelka
Robert Kozar
Michael Krainak
Martin P. Kress
S. M. Krimigis
Donald J. Kutyna
Alan Ladwig
Cynthia C. Lee
Robert B. Lee, III
Thomas J. Lee
William B. Lenoir
Byron P. Leonard
Gale Lewis
LeNoir Lewis
Morris L. Lile
Bruce D. Little
Jane Liu
John Logsdon
Rebecca J. Lowe
William R. Lucas
Henry Lum, Jr.
Valerie Lyons
Christopher P. Mackay
Robert Mackin
Jeremiah J. Madden
Gray Marsee
Rebecca McCaleb
Forrest McCartney
Roslyn L. McCreary
Helen McConnaughey
John H. McElroy
Joseph T. McGoogan
John L. McLucas
Ann Merwarth
James F. Meyers
Roger Meyers
Lon F. Miller
Royce E. Mitchell
Herbert Mittelman
Tom Moore
David Moore
Thomas Moorman
James R. Morrison
Walter E. Morrow
George Morrow
Bruce Murray
Thomas J. Murrin
Dale D. Myers
Roger Myers
Joyce Neighbors
Norman F. Ness
William C. Nettles
James C. Newman, Jr.
Jerry R. Newsom
Thomas E. Noll
John E. O'Brien
Edward O'Connor
Michael O'Neal
Michael Oben
Arthur F. Obenschain
James B. Odom
David Olney
O. J. Orient
Angel Otero
Thomas O. Paine
Don Palac
S. Paul Pao
Sidney F. Pauls
Vicki Pendergrass
C. Perigaud
Richard H. Peterson
Victor L. Peterson
James Phillips
David R. Picasso
Andy Pickett
Sasi Pillay
Kevin Plank
Alexander Pline
Don Polac
Sam Pollard
Lamont R. Poole
Fred Povinelli
Lonnie Reid
Kerry Remp
Leonard Ricks
William E. Robbins
Linda Robeck
Ralph H. Robinson
Neal Rodgers
Thomas F. Rogers
James T. Rose
Stanley G. Rosen
Lawrence J. Ross
Joseph H. Rothenberg
C. T. Russell
Stephen M. Ruffin
George Russell
Kurt Sacksteder
Carl Sagan
Vincent V. Salomonson
Stanley Sander
Neal Sanders
Stephen P. Sandford
Pat Scheuermann
Harrison H.Schmitt
B. A. Schriever
Christopher J. Scolese
John P. Scully
Robert C. Seamans, Jr.
Michael G. Shafto
Willis H. Shapley
Joseph C. Sharp
Kirk Sharp
Brewster Shaw
Joe Shaw

Joseph Shea
Thomas A. Shull
Richard J. Siebels
Robert Sieck
Bill Sikora
Allan Silver
Louis E. Simmons
J. A. Simpson
Joel R. Sitz
James Slavin
Nancy E. Sliwa
Mike Smiles
L. Dennis Smith
Gerald Smith
Richard Smith
Michael D. Smock
D. Thomas Snyder
Robert Snyder
Kenneth A. Souza
Roy Spencer
Joel Sperans
Suzanne Spitz
Russ Springham
Robert Staehle
Anne K. St. Clair
Thomas Stafford
Angela Stewart
Andrew Stofan
Edward C. Stone
Anthony Strazisar
William Strobl
Robert L. Swain
Clarence "Cy" Syvertson
Steve Szabo
Michael E. Tall
John Taylor
William F. Taylor
Thomas D. Taylor
Samuel M. Tennant
Charles E. Thienel
A. S. W. Thomas
Gene Thomas
Ron Thomas
Walter Thomas
John D. Thompson
J. R. Thompson, Jr.
Marco Toral
Carmen O. Torres-Nisbet
John Townsend
James H. Trainor
Paivi Tripp
Richard H. Truly
Susan Turner
Daniel Tweedt
Donald Urasek
James A. Van Allen
Joan Vernikos
Edgar G. Waggoner
Carrie K. Walker
Jerry Wall
Joyce Wanhainen
Sandy R. Webb
Mark Weislogel
Martin Weisskopf
Vern Weyers
Douglas W. Whipple
David R. White
John White
Lynne White
David Whitten
Alan W. Wilhite
C. Wayne Williams
Charles Williams
Keith Wilson
Murray J. Wilson
Fred S. Wojtalik
Lowell Wood
Jerry Wood
Timothy G. Wood
William H. Wood
James Wood
John F. Yardley
John Yin
Tom Young
V. Zlotnicki
Henry N. Zumbrun

Appendix V
Bibliography

American Institute of Aeronautics and Astronautics. **U.S. Civil Space Program: An AIAA Assessment**. March 1987.

Bilstein, Roger E. and Frank W. Anderson, Jr. **Orders of Magnitude: A History of the NACA and NASA, 1915-1990**. NASA SP-4406. 1989.

Byerly, Jr., Radford. (ed.) **Space Policy Reconsidered.** Westview Press. 1989.

Center for Strategic and International Studies. John H. McElroy and Brent Scowcroft, Chairmen. **A More Effective Civil Space Program**. May 1989.

George C. Marshall Institute. **New Directions in Space: A Report on the Lunar and Mars Initiatives**. 1990.

National Academy of Public Administration. Samuel C. Phillips, Chairman. **Effectiveness of NASA Headquarters: A Report for the National Aeronautics and Space Administration**. February, 1988.

National Academy of Sciences, National Academy of Engineering, Committee on Space Policy. H. Guyford Stever, Chairman. **Toward a New Era in Space: Realigning Policies to New Realities, Recommendations for President-Elect George Bush**. National Academy Press. 1988.

National Aeronautics and Space Administration (NASA), Advisory Council, Life Sciences Strategic Planning Study Committee. Frederick C. Robbins, Chairman. **Exploring the Living Universe: A Strategy for Space Life Sciences**. 1988.

NASA, Advisory Council, Space and Earth Science Advisory Committee. **The Crisis in Space and Earth Science: A Time for A New Commitment**. November 1986.

NASA, Advisory Council, Task Force on International Relations in Space. **International Space Policy for the 1990's and Beyond**. October 1987.

NASA, Advisory Council. John L. McLucas, Chairman. **Report of the Task Force on Space Transportation**. December 1989.

NASA, Center Science Assessment Team. D. James Baker, Chairman. **Science at NASA Field Centers: Findings and Recommendations on the Scope, Strength, and Interactions of Science and Science-Related Technology Programs**. May 1988.

NASA, History Division. **Evolution of the NASA Institution**. January 1988.

NASA, Office of the Administrator. **Results of the Life Support Management Working Group, Volumes I and II**. June 1989.

NASA, Office of Aeronautics, Exploration and Technology. **Space Exploration Initiative: Technology Needs and Plans; A Report to the U. S. Senate**. Summer 1990.

NASA, Office of Exploration. Annual Report to the Administrator. **Beyond Earth's Boundaries, Human Exploration of the Solar System in the 21st Century**. 1988.

NASA. **Report of the 90-Day Study on Human Exploration of the Moon and Mars**. November 1989.

NASA. Samuel C. Phillips, Chairman. **Summary Report of the NASA Management Study Group: Recommendations to the Administrator.** December 1986.

NASA. Sally K. Ride. **Leadership and America's Future in Space.** Report to the NASA Administrator. August 1987.

National Commission on Space. **Pioneering the Space Frontier.** Bantam Books. May 1986.

National Research Council (NRC), Committee on Human Exploration of Space. **Human Exploration of Space, A Review of NASA's 90-Day Study and Alternatives**. National Academy Press. 1990.

NRC, Space Science Board, Committee on Space Biology and Medicine. Jay Goldberg, Chairman. **A Strategy for Space Biology and Medical Science for the 1980's and 1990's**. National Academy Press. 1987.

NRC, Space Science Board. **Space Science in the Twenty-First Century: Imperatives for the Decades 1995-2015, Overview**. National Academy Press. 1988.

NRC. **U.S. Global Change Research Program, An Assessment of the FY 1991 Plans**. National Academy Press. 1990.

Truly, Admiral Richard H. **A Statement to Subcommittee on VA-HUD-Independent Agencies, House Committee on Appropriations**. March 1990.

U.S. Congress. **National Aeronautics and Space Act of 1958, as Amended**. (PL-85-568, 85th Congress, H.R. 12575. August 29, 1958. 72STAT426.) January 1990.

U.S. Department of Commerce. **Commercial Space Ventures: A Financial Perspective**. April 1990.

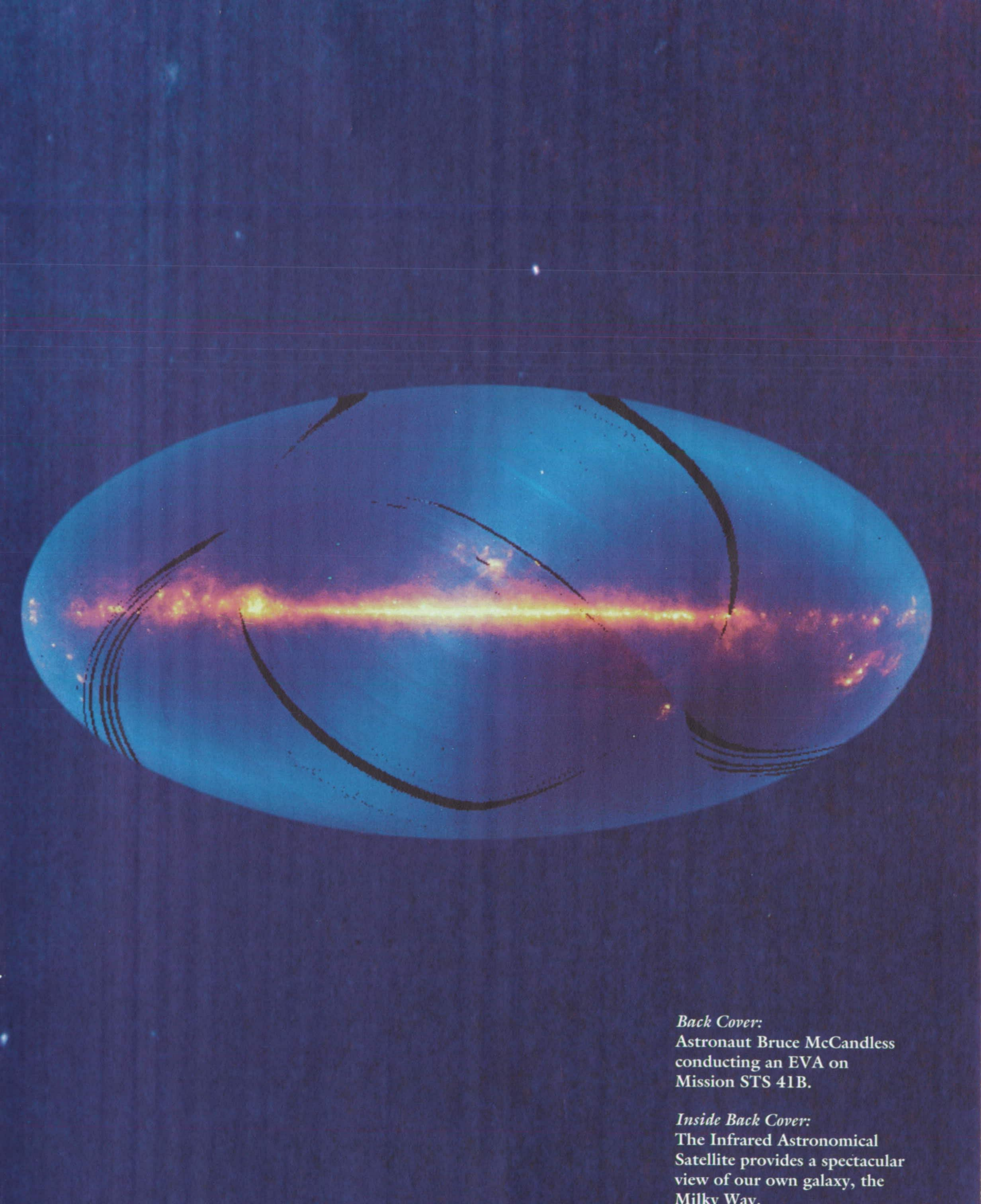
U.S. Department of Defense, Office of the Under Secretary of Defense for Acquisition. **Report of the Defense Science Board, 1989 Summer Study on National Space Launch Strategy**. March 1990.

U.S. President's Pay Agent (Advisory Committee on Federal Pay) Annual Report. **Comparability of the Federal Statutory Pay System with Private Enterprise Pay Rates**. 1989.

U.S. Presidential Commission. William P. Rogers, Chairman. **Report of the Presidential Commission on the Space Shuttle Challenger Accident**. June 1986.

U.S. Space Task Group. **Report to the President: The Post-Apollo Space Program: Directions for the Future**. U.S. GPO. September 1969.

White House, Office of the Press Secretary. Fact Sheet. **Commercial Space Launch Policy**. September 1990.



Back Cover:
Astronaut Bruce McCandless conducting an EVA on Mission STS 41B.

Inside Back Cover:
The Infrared Astronomical Satellite provides a spectacular view of our own galaxy, the Milky Way.