Summary and Principal Recommendations of the Advisory Committee on the Future of the U.S. Space Program: Advance Copy

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ADVANCE COPY

OF THE

SUMMARY AND PRINCIPAL RECOMMENDATIONS

OF THE

ADVISORY COMMITTEE ON THE FUTURE OF THE

U. S. SPACE PROGRAM

DECEMBER 10, 1990

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 fuel cell exploded during the mission of Apollo XIII 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, say, the tangible value of studies in astronomy -- and so on.

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 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.

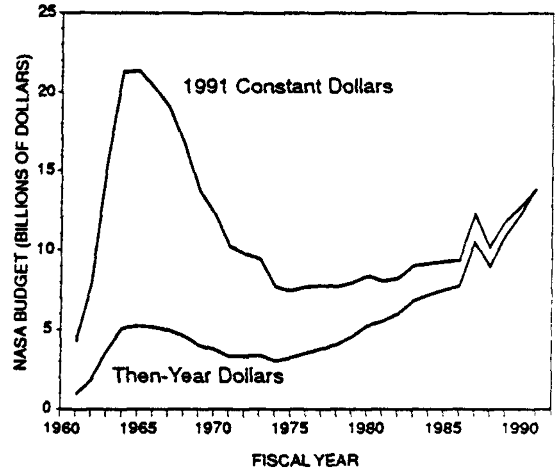
It can be argued that at least some of these benefits can be reaped by other more direct means. If the objective is to stimulate education, then why not give the money being spent on space to our schools? If the objective is to study the stars, then why not build more and better telescopes here on earth? 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 million 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

FIGURE 1.

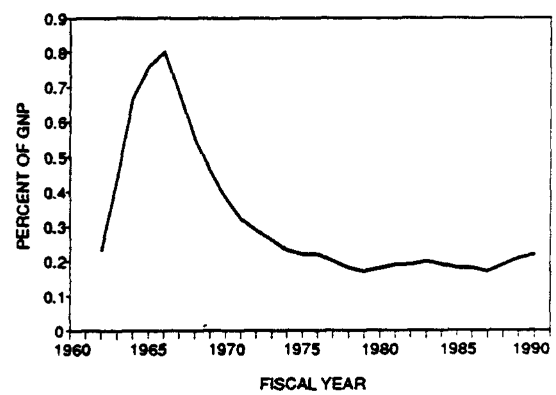
NASA Budget Trend
(Dollars)



Source: NASA

FIGURE 2.

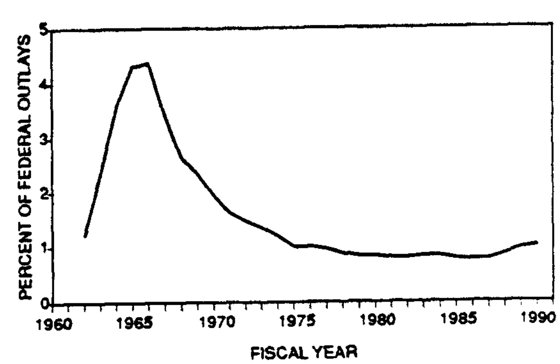
NASA Budget Trend
(Percent of GNP)



Source: Congressional Budget Office - GNP
NASA - NASA Budget

FIGURE 3.

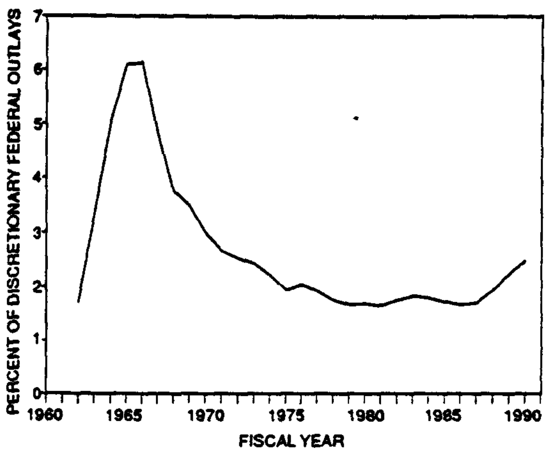
NASA Budget Trend
(Percent of Federal Spending)



Source: NASA

FIGURE 4.

NASA Budget Trend
(Percent of Total Discretionary
Federal Spending)



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

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.

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 spaceflight, 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 spaceflight.

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 node -- 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 that offers increased payload capacity and is 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.

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 implement fully 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
- a Mission to Planet Earth (MTPE) focusing on environmental measurements
- 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
- a significantly expanded technology development activity, closely coupled to space mission objectives, with particular attention devoted to engines
- a robust space transportation system

Principal Recommendations Concerning Programs

With regard to program content, it is recommended that:

- the strategic plan for science currently under consideration be implemented
- a revitalized technology plan be prepared with strong input from the mission offices, and that it be funded

- 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

- 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.

- 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

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

- defer or eliminate the planned purchase of another orbiter

- place the Mission from Planet Earth on a "go-as-you-pay" basis, i.e., tailoring the schedule to match the availability of funds

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

- 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

- NASA management review the mission of each center to consolidate and refocus centers of excellence in currently relevant fields with minimum overlap among centers

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.

  - an Associate Administrator for Exploration be established, whose responsibilities include robotic and manned exploration of the moon and Mars.

  - 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.

  - 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.

- 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.

- a systems concept and analysis group reporting to the Administrator of NASA be established as a Federally Funded Research and Development Center.

- 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).

In summary, we recommend:

1) Shifting the priorities of the space program to place primary emphasis on science.

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 International, 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 Incorporated 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 Co. 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 M.I.T.

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 P&C 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, Stanford, 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 Incorporated, 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, a Distinguished Member of the Technical Staff at 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 A.M. 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.

Technical and Administrative Support:

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

Appendix II

TERMS OF REFERENCE

ADVISORY COMMITTEE ON THE FUTURE U.S. SPACE PROGRAM

Purpose

The purpose of the Advisory Committee on the Future 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 chairperson.

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
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 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 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
Stan 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
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 Woods
John F. Yardley
John Yin
Tom Young
V. Zlotnicki
Henry N. Zumbrun

Appendix V

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