3. **Space Science Program**. As you have already undoubtedly picked up, we are in a dilemma on space science at NASA because it seems to be strongly supported by the White House (President, Science Adviser, OMB, etc.) but poorly supported by the Congress. Congress seems to go for the Applications [5] Program, the Aeronautics Program, and the so-called "space spectaculars" such as Apollo, Skylab, ASTP, Viking, etc. Space solar power is an excellent example of such a spectacular and is a case in point. Apparently the reason for this dilemma is that OMB feels the Applications Program should more properly be left to the user agencies or to industry, which are always slow to support new satellite programs, whereas, Congress, especially the Space Committees, doesn't care about the user agencies because that's not their responsibility. In science, however, we have a clear mandate since we are our own user but somehow Congress recognizes that science of any kind is not popular among the general public (ask Herb Rowe for polls on that subject) and although low-profile science can get through Congress fairly easily, large bites such as the space telescope, JOP and Viking Follow-on (perhaps) seem to have difficult times. I have no pat solution for this dilemma except to continue to work the problem as we have been doing.

4. **Senate Power Base**. I used to raise my eyebrows when Jim Webb talked about a "power base" in Congress. Having just come from academia, this seemed a crude way of operating; however, after being here six years, I'm beginning to see what he meant. In the Senate especially, but to some degree also in the House, there are individuals who seem to sway the rest of the body. In the House this is less clear but certainly Tip O'Neill, George Mahon and to a lesser extent, Jim Wright, could be put into this category. In past years, Wilbur Mills and Eddie Hebert served that function, but I'm not sure their successors have quite moved into such strong positions.

Incidentally, Tiger Teague has a great deal of respect in the House, and when he is willing and able to acknowledge this respect, he can be very helpful; however, in recent years his health has been a definite handicap and this is one of our problems at the moment in the House Appropriations Subcommittee. Tiger says he is not going to run again, but when he gets his lightweight leg and his spirits improve, I wouldn't bet against his running.

In the Senate, however, the situation has changed drastically. When I first heard that Senator Proxmire was going to be [6] Chairman of our Appropriations Subcommittee, it looked like "the end of the world" until we began to work the problem. It began to be clear that the ex officio votes on the Proxmire Subcommittee by the Senate Space Committee Chairman and Majority Leader were enough to swing the rest with no problem at all. The votes typically were 8 or 9 to 1, with Senator Proxmire's being the only negative vote. The loss of Senator Moss was considerable even though he did not have the leverage that some of the other Senators had. He was the Chairman of the Democratic Caucus and the #3 democrat in the Senate and on occasion could swing a fair number of votes. Senator Goldwater, of course, was the undisputed conservative leader in the Senate and consequently both sides of the house could be swayed by him. So it was not only the loss of Senator Moss but the loss of those ex officio votes that caused us to lose leverage in the Senate. Senator Stevenson is just learning the business but I think in time he, along with his strong staff members, should be great support especially if they are able to involve Senator Magnuson in helping him to influence some of their colleagues. Meanwhile, I'm afraid we are forced into falling back on the Proxmire Subcommittee itself.

Although we have strong support in Senator Stennis and, I believe, Senator Sasser on the Democratic side and I think all four on the Republican side, this is not enough to be considered strong support in the sense of adding in programs that the House may have taken out. This latter situation occurred many times in the past through the help of Senators Moss and Goldwater, but this year we simply can't count on it. On the other hand, I think the support is strong enough so that they are not likely to make further cuts.

The one redeeming feature in the Senate reorganization is the position of Senator Cranston as Majority Whip. He is a strong space supporter in his own right but, being a California Senator, has vested interests as well. Senator McClellan also has a great deal of influence as does Senator Stennis but those are primarily on the conservative side of the House and the number of conservative democrats is becoming fewer each year. Senator Jackson, of course, [7] is powerful as in earlier years but so far has not had any impact on NASA's programs. Senator Cannon has moved up in stature since his recent reelection, having been one of the few western democratic Senators to be returned to the Senate. I had hoped that he would end up in one way or another as Chairman of one of our committees but that was not to be. I think becoming better acquainted with Senator Cannon can be a great help both by influencing votes in the Appropriations Committee and, of course, in the Commerce Committee itself.

These are all things that must be tracked very carefully, and I'm afraid roles are changing so rapidly that I can only alert you to the problems. Pete Crow and Joe Allen, I think, understand the situation pretty well and should be able to help make the appropriate contacts. Judy Cole, if she stays, is excellent on the G-2 and has a very good working relationship with the staff of the Senate Budget Committee. Although run by Senator Muskie, it is not yet clear how much impact it will have.

5. **Aeronautics.** I won't dwell on this subject since Al Lovelace is very familiar with the problem, but simply mention that we need to revive the fundamental work that the old NACA used to do. (The Aeronautical Centers should be at least as good as NRL is to the Navy, but so far not a single member of the NASA organization has been elected to the National Academy of Science as has Herb Friedman of NRL.) It is not clear how to do this but, of course, it is related to the institutional problem of bringing in stronger scientific and creative new talent.

6. **The Shuttle Launch Phase.** Undoubtedly Al must have mentioned to you that my biggest concern on the Shuttle at the moment (aside from operational costs) is the technical difficulties involved in the launch phase. As you know, Houston is the lead Center for Shuttle development and performed very well on the Apollo spacecraft and the LM, and also carrying out operations in space. They had very little to do with the development of the Saturn launch vehicle, which was done out of Huntsville. Wernher von Braun and the people [8] he brought with him both from Germany and from within the United States had an in-house capability second to none in the world.* As a result, if you look back in the records, you will find very few difficulties with the Saturn itself and, in fact, the extra weight-carrying margin of the Saturn saved the Apollo program more than once. Incidentally, neither George Low nor John Yardley has had this launch vehicle background, and so with the loss of Rocco Petrone, we have never really had anybody in Headquarters who had much experience in this area.

I guess the question is, why do I consider this different from space problems generally? It comes down to something like the following: With the spacecraft itself during its flight in space and its landing and its attitude control system and its life support systems, etc., we had the capability to build highly redundant systems. So if we ran into a problem, there was usually time to find a "workaround" and, in fact, in every case except the fire on the ground, we managed a workaround good enough to bring the astronauts back. On the other hand, look at all of the things that went wrong during the Apollo/Skylab series. If we hadn't had this redundancy, we would have lost essentially every mission. In the case of the booster, however, there was no time for any significant workarounds on the ground. There is some redundancy built in but not an excessive amount. Therefore, testing analyses and engineering intuition have been the backbone of the launch vehicle business from the days of the V-2. Clearly the combined vehicle consisting of the two solid rockets, the external tank, and the Shuttle is the most complicated launch vehicle ever built. My big concern is whether or not analysis and testing on the ground are sufficient to ensure the reliability of this phase of the flight profile or whether engineering judgment and experience which were the hallmark of the von Braun group aren't still necessary for a guaranteed success. So far I have discussed this with Al Lovelace and Walt Williams only. Walt, of

*[handwritten note] Korolov played the same role in the U.S.S.R. When he died, the Soviets were not able to make a single new launch vehicle work.

course, has had extensive experience with Air Force launch vehicles but again nothing like the experience of the Huntsville group. [9] Perhaps I'm overly concerned about this problem, but when you consider the value of the payload even on the first flight and the consequences of a failure, I'd have to put it as one of my high-priority items for the near term.

7. **Pet Projects.** There are a number of things which I have tried to keep going because I believed in them, but most had a low level, which you may want to discontinue:

a. **Hypersonic Transport.** I have always felt, aside from environmental problems, that it would be a rather straightforward development to build a commercial vehicle for long-distance travel (say from New York to Delhi or from New York to Bahrein), but I'm not sure that the airplane is the best way to do it. I have the uncomfortable feeling that it might be simpler to remove the energy from a returning space vehicle by means of high-drag devices such as parachutes, blunt bodies, retrorockets, etc., rather than with wings. This is heresy at NASA but you must understand that I came up through the rocket route, not the airplane route. I did, however, go to the trouble of bringing in the parachute people to see whether indeed parachutes could be built that would allow large transports to be dropped through the atmosphere in much the same way as the Apollo capsule, and it always seems to be technically feasible but on the surface more optimal than the Shuttle itself. Needless to say, I didn't want to emphasize this in the middle of the Shuttle program.

b. **Heavy Lift Launch Vehicle.** For putting large quantities of payloads in space, it seems there are better ways of doing this than the Shuttle itself since the missions are all one way and all you need to recover are pieces of the launch vehicle itself. This can be done easily with parachutes. We might easily gain a factor of 10 to 1 over the cost per pound now required by the Shuttle.

c. **Solar Sailing.** I am sure you remember with some ambivalence Dick Garwin partly for his abrasive tone but also for his tremendous creativity. In 1972, he strongly urged me to look into the possibility of using lightweight [10] materials to "sail" around the solar system. It took four years for the NASA "system" to respond. Bruce Murray picked it up and is now running with it. In my opinion this will be the way we will move out to Mars and other planets in the future even when we decide to go there with manned missions.

d. **Personal Communication Systems.** I really do believe that some day we will want to have person-to-person communications systems, not necessarily for the wristwatch variety but at least of the pocket calculator variety in which any person can dial any other person long distance from his car, from the golf course or wherever. This, I think, is a straightforward use of a high-powered, highly directional stationary satellite. I don't believe cost tradeoffs of this system have been made, and I'm not sure how much a person would pay for such a convenience.

e. **Technology Transfer.** The early studies made on the relationship between high technology and national productivity were very exciting indeed. The whole problem is not very well understood by economists and, I do not believe, other people in government. People seem to equate high technology with new inventions or new products instead of with productivity, and the picture gets all out of proportion. Paul Kochanowski, a former Brookings Fellow at NASA, understood the problem very well and I learned what little I know from him. It does seem to me that the impact on our economy of the technology such as NASA develops and as portions of DoD develop is absolutely enormous. I therefore have encouraged further economic studies of this process but you may wish to discontinue it.

f. **Broadening NASA's Responsibility.** As Al has probably indicated to you, I've always felt that NASA's managerial talents as well as some of its technical talents have been underutilized, and we ought to move into areas that are now the responsibilities of other agencies. This is a severe bureaucratic problem, and I'm not sure you'll want to get into that but if you do, the best time to do it [11] is during a change of Administration, as you well know, before the bureaucracy becomes firmly entrenched.

8. **Public Affairs.** During the Apollo days and before, NASA provided an excellent public information service to the media and, generally speaking, the public was well in-

formed about the so-called "space spectaculars." At this point in time though we need to move to a public *relations* program; that is, an aggressive program to inform the public as to how their money is being spent and what they get for it. This is a much different problem and I have asked Bob Newman and Herb Rowe to put together a program plan which presumably has been done by now but is awaiting guidance. The last session we had brought out the fact that the focus on this aggressive program ought to be on applications and spinoffs, but we really hadn't come down to the heart of the matter and that is how to have one or two simple themes which describe NASA's contributions to the nation. My own feeling is that we need outside expertise on this one and although we brought in Burson-Marsteller, a first-rate Chicago outfit, I value the advice of Jim Mortensen of Young and Rubicam much more highly. Jim is a broad, thoughtful person interested in the space program and is willing to contribute his service freely when he has the time available. Todd Groo's experience in this area is also helpful. All of these latter are more creative than Herb and I have indicated to him that I wanted all of these other men to be heavily involved in any program plans for the future. You may wish to change that.

There are other items that I could mention here and still more that I will think of before I leave, but I expect I have covered 90 percent of the biggest issues.

James C. Fletcher

Document IV-16

Document title: Task Force for the Study of the Mission of NASA, NASA Advisory Council, "Study of the Mission of NASA," October 12, 1983, pp. 1-9.

Source: NASA Historical Reference Collection, NASA History Office, NASA Headquarters, Washington, D.C.

The NASA Advisory Council and its standing committees are descendants of the National Advisory Committee for Aeronautics (NACA), which, through its technical committees, oversaw the research conducted by NACA's Langley, Lewis, and Ames research laboratories. Lacking the statutory authority of its predecessor, the NASA Advisory Council acts as an informal "board of directors" to the NASA administrator. The council's 1983 "Study of the Mission of NASA," chaired by Daniel J. Fink, was a detailed and comprehensive effort to chart a course for the U.S. civil space agency in a changed political and technical environment. It reviewed in a comprehensive manner the overall mission of the agency and recommended alterations for its activities for the next 20 to 40 years in both aeronautics and space. While the task force members said they unanimously agreed with the elements of the mission statement that emerged, they admitted some disagreement as to whether the mission area of "Exploration of the Solar System" should be viewed as an overarching theme to guide the forward technological thrusts of the agency. While some strongly endorsed this as a central focus for NASA's future space activity, the majority were concerned that such a specific identification would result in the diminution of the other important missions. A special area of concern was the space shuttle, and the report recommended that a new NASA organization, with resources "fenced" from those of the rest of the agency, be established to manage the shuttle program.

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[1]

Study of the Mission of NASA

EXECUTIVE SUMMARY

A task force of the NASA Advisory Council was authorized by the NASA Administrator in July 1982 to study the long-range missions of NASA and present recommendations for the future course and direction of the Agency over a period of the next 20 to 40 years. The Task Force membership consisted of selected members of the NASA Advisory Council, augmented by additional participants representing the requisite areas of expertise.

1. The Mission of NASA

The Task Force recommends this "Mission of NASA" that rests on current statute and policy and provides a framework for NASA's activities for the next 20 to 40 years.

Mankind has acquired the ability to move within and beyond the confines of the surface and the atmosphere of Earth, creating apparently limitless opportunities for beneficial human activity. In this regard, NASA has a dual mission—in space and the atmosphere—portions of which are overlapping.

NASA's space mission is to conduct activities on behalf of the people of the United States in collaboration with other nations, to:

- explore the solar system and study its planetary processes, including, as appropriate, those governing the Earth, for the benefit of humankind,
- pursue a program of fundamental scientific research in space to expand human knowledge,
- plan and implement space technology programs and research into the use of the environment of space in order to provide for the continued advance of the national space capability and its exploitation for public and commercial purposes,
- and, to achieve these ends, create the capability for an expanded human presence in space and develop and assure the operation of launch and space vehicles.

NASA's mission in aeronautics is to maintain, and augment as appropriate, an aeronautics research and technology program which contributes materially to the U.S. leadership in civil and military aviation.

[2] The Task Force believes that it is inevitable that human habitation will eventually extend beyond the confines of the Earth in many ways and on a scale far larger than is currently envisioned. Although it may not now be productive to debate the specific nature or the timing of this most dramatic of all human ventures, it is appropriate to use such a venture as a distant goal to guide our search for an understanding of the solar system and to stimulate the further advance of humankind.

2. Key Missions Considered

In arriving at this broad statement of the Mission of NASA, the Task Force considered a wide range of specific mission areas:

- Exploration of the Solar System, Including the Planet Earth, for Human Benefit
- Fundamental Space Science
- Space Technology
- Space Applications
- STS Operations
- Aeronautics
- Human Spaceflight Research
- International Relationships.

a. Exploration of the Solar System, Including Planet Earth, for Human Benefit

NASA's mission in space science can be considered in two distinct parts: one is space science conducted to contribute directly to human welfare and national need, and the other is fundamental space science conducted to expand human knowledge. The first is currently focused on solar system exploration, including the planet Earth, while the second covers the full range of space science fields, from astronomy to space physics.

NASA's mission in the exploration of the solar system itself contains two related parts, which together provide a major objective for the next half century. The first involves exploration of the solar system with the eventual goal of utilizing the resources and knowledge of space for human benefit. The second brings a planetary perspective to our own planet and leads to the goal of understanding those processes involved in global surface and atmosphere change especially important to living systems.

To accomplish this long-range mission, the Task Force recommends that:

• The United States, in collaboration with other interested nations, vigorously pursue a program of exploration and understanding of the solar system for ultimate human benefit.

[3] • A more aggressive pursuit of the technologies of robotics, teleoperation, and machine intelligence be undertaken to maintain a proper lead and balance in the design of NASA programs.

• NASA accept a leadership role in major aspects of the study of the planet Earth, in particular in those areas which concern global changes of importance to the support of human life.

• Adequate funding be provided for ground-based, laboratory, and theoretical work as well as for space systems.

• NASA seek a lasting national commitment in order to achieve these goals, which will require new approaches to project procedures and budgetary policies including steady funding levels and program continuity.

b. Fundamental Space Science

In fundamental science, NASA shares a responsibility with the National Science Foundation, with the break in responsibility occurring at the construction of spacecraft and space instruments. Working relations are generally satisfactory, but policy interactions have been limited. This division of responsibility has left a gray area of ground-based observations and theoretical and laboratory work, all essential for realizing the full advantages of space missions. Problems also exist in the provision of adequate funding to maintain effectiveness in research capabilities built laboriously over decades. The Task Force sees no simple solutions to these problems, but is convinced that the effort to find solutions must continue.

The Task Force recommends that:

• Space science must remain a principal part of NASA's mission because research in space science has become a central element of scientific research in the United States and the prospects for future major advances in this field remain bright.

• Adequate and stable levels of funding for ground-based, laboratory, and theoretical research, a key part of NASA's scientific program, be provided independently of the fluctuating needs for spacecraft and instrument construction.

• NASA take a lead role in assuring that the activities sponsored by NASA and NSF are properly coordinated.

[4] **c. Space Technology**

The Task Force considered whether NASA should support the space technology needs of other government agencies, both military and civil, and the private sector. A recent study by the Aeronautics and Space Engineering Board of the National Research Council recommended that NASA's program be redirected to the needs of the broad national space constituency, and endorsed the concept of a role in space technology analogous to NASA's traditional role in aeronautics.

The developing capability to conduct space experimentation on or with the support of the Shuttle provides NASA with a unique resource for space R&T and one that is critical to the technology needs of many space users. A space station could provide an even greater laboratory in space—a "field center"—that would be truly unique in this regard. The Task Force concurs with the ASEB in its recommendation that NASA's mission in space R&T be supportive of total national space requirements.

The Task Force recommends that:

• NASA's mission in space research and technology be supportive of total national requirements, considering future needs of the civil, military, and commercial sectors. In terms comparable to those for NASA's mission in aeronautics, NASA should have the mission in space R&T to:

- Fund, direct, and implement space research, technology, and demonstration programs in support of its own and other civil space activities; and support DOD technology needs where the results have broad application and are not duplicative of other government-funded effort.

- Encourage and facilitate, together with other appropriate agencies, the transfer of space R&T results to and within U.S. industry.

- Manage, maintain, and operate space research, development, test, and evaluation facilities. Use of the Space Shuttle and eventually a space station as a laboratory facility in space should be exploited for development of new space technologies.

• Funding for NASA space R&T be increased selectively to permit implementing these recommendations. The following criteria are suggested for identification of technologies to be accorded high priority:

[5] - The technology is in the national interest and will fill a reasonably established future requirement.

- The technology offers payoff significantly greater than that presently available at a reasonable cost and is at least comparable in payoff and cost to alternative approaches to the same end.

- The technology program is not likely to be undertaken, on a timely basis, by others, either public or private.

- The technology is in an area in which NASA already has a demonstrated capability, or if in a new area, is one in which NASA can readily build the capability and expertise without duplicating an equivalent capability outside.

• Funding augmentations in high-priority technologies be provided only after reasonable assurance that ongoing technology developments of little potential value are being phased down and that a base level of more basic research is being maintained across the full spectrum of disciplines to assure that new technology opportunities applicable to future missions are not missed.

d. Space Applications

There appears to be little question that NASA should perform research and technology development in major space applications areas such as telecommunications, meteorology, Earth resources, and materials processing in space. However, there is much concern about how far NASA should go to provide utility demonstration and early operation of space applications systems.

NASA's role in space applications should be compatible with the overall mission of NASA. The present assumption is that NASA's primary focus should be on space R&D with involvement in operations only if necessary. The other working assumption is that NASA's primary emphasis should be on the civil side, although support of military and other defense interests is not excluded.

The Task Force recommends that the NASA mission include the study of space and space technology for civil applications, by:

• Continuing the identification of possible civil applications of potential value and by conducting preliminary studies of potential benefits, users, and markets. This includes taking the leadership in systematic reviews of existing and possible civil applications of space

[6] • Conducting or supporting research and technology development on essential components and subsystems of space and ground systems for civil space applications.

• Conducting, with suitable cooperative arrangements with the private or public agencies, tests, demonstrations, and experimental user operations of new types of spacecraft, spaceborne systems, and ground systems for civil space applications in cases where:

- Potential advantages, uses, and users have been identified.
- The private sector or other agencies cannot reasonably be expected to pay the full cost.

Administration recognition of this mission of NASA should be sought.

• Arranging for the transfer to private or public agencies, as appropriate, of useful applications systems employing space technologies, unless it is in the national interest for NASA to become the operating agency.

e. STS Operations

Realization of the maximum operational efficiency for Shuttle operations is an immediate task which requires a major amount of attention from senior NASA management. A continuation of the current STS management approach might create a serious diversion of NASA resources and attention from its more traditional roles of aeronautics and space R&D and space exploration and experimentation. The view also has been expressed that NASA is not the proper organization to achieve the operating efficiencies, levels of customer satisfaction, or degree of market development desired. Therefore, resolution of the technical and management issues involved in Shuttle operations can have a major impact on future NASA missions.

Various options for the management of STS operations were examined by the Task Force, including commercial management by an industrial organization, full operation by DOD, creation of a new Federal agency for Shuttle operations management, establishment of a quasi-government corporation, creation of a new organization within NASA, and continuation of the present management arrangements in NASA.

The study group concluded that the present small size of the Shuttle fleet, its lack of maturity and high costs of operation, and the lack of DOD interest in assuming full operating responsibility, all militate against shifting Shuttle operations outside [7] of NASA in the near future. The potential for future diversion of management attention and resources from the STS to other NASA programs suggests the advisability of further segregating the Shuttle operating management organization from the rest of the NASA organization, at least as an evolutionary, timely step.

The Task Force recommends that:

• A new NASA organization be created at the appropriate time within NASA to focus on Shuttle operations and utilization, including marketing activities and sustaining engineering support. This organization, which should be headed by a Deputy Administrator, should have fenced manpower, finances, and facilities

• The Shuttle Operations organization continue to enhance customer services and market development activities through the application of resources both internal and external to NASA as appropriate. Consideration should be given to contracting out the market development activities

• The Deputy Administrator for Shuttle Operations be charged with proposing the evolutionary steps for future management of Shuttle operations

• The Shuttle operations organization not undertake future STS development activities, such as a follow-on Shuttle or new launch capability. It should, however, help define future requirements for such major improvements

• The value of the STS as a national resource due to its unique capabilities to provide for manned spaceflight, defense missions, space science support, and research and technology development in the space environment, as well as its special capabilities for satellite retrieval and spacecraft servicing, be recognized. The total costs associated with this national resource value should not be charged to the Shuttle's launch service users.

• As markets for the STS develop, NASA consider shifting pricing of Shuttle services towards an incremental (i.e., Institutional) cost basis. This is the usual practice in NASA research facilities and, given the national resource character of the Shuttle for civil and military Government programs, is more appropriate than pricing on the basis of total recovery of recurring costs (industrial funding).

[8] **f. Aeronautics**

When the Task Force was established, the issue of NASA's mission in aeronautics was thought to be one that would require a great deal of attention as a result of questions raised in recent years regarding the role of the Federal government vis-a-vis that of the private sector. However, a broad policy statement on the Federal mission in aeronautical R&T has been issued by the Office of Science and Technology Policy, which resolved most of the issues. The Task Force addressed two derivative issues: demonstration of technology for civil aviation, and effective relations with the DOD.

The Task Force recommends that:

[9] • NASA's mission in aeronautics, subject to specific approval, include support to the industry in civil aviation technology demonstration programs provided that they are in the national interest, the industry cannot effectively conduct the programs without that support, and the support fits naturally within NASA's capabilities.

• NASA continue to assist, communicate with, and cooperate with all branches of the DOD in all matters relating to aeronautics. The first priority should be in basic aeronautics research and technologies, and should include providing access to and utilization of both human resources and laboratories and other physical test facilities as appropriate. The second priority should be in mission-oriented systems work, as requested or when special expertise or facilities are available.

g. Human Spaceflight Research

While the effects of spaceflight have proved to be manageable in flights of the durations experienced up to now, there are additional concerns when prolonged duration spaceflight, as in permanent space stations or eventually in interplanetary flight, is considered. Five areas which require intensive research include: prolonged exposure to zero gravity; provision of oxygen, food, and water; provision of an adequate social and organizational environment; exposure to ionizing radiation; and extra-vehicular activities.

The Task Force believes that it is inevitable that people will seek to explore the solar system, not only by remote sensing or even by automated acquisition of samples, but by being there, and thus ultimately extend the domain of human life beyond the confines of the Earth. The requirement for mission durations ranging from months to years is implicit. Given the significance of the issues and the lengthy interactive R&D process required, the Task Force recommends that:

[9] NASA give high priority to the continuing program needed for the development of the capability to keep people healthy, effective, and well motivated over the long periods required for manned exploration of the solar system. The development of effective countermeasures for the disturbances associated with zero gravity requires research ex-

tending over many years, and must be addressed now to avoid later constraints on manned exploration missions.

h. International Relationships

Bearing in mind that one of the basic goals of the National Space Policy is to promote international cooperative activities in the national interest, the Task Force examined the international aspects of NASA's roles and missions. NASA's international role is very important to the maintenance of the image of the United States as the technological leader of the free world. There is need for more binding commitments in our cooperative activities in space ventures with other nations. Further, the U.S. policy on technology transfer was observed to be counter-productive because it limits other nations in their ability to procure U.S. space products rather than develop such products domestically.

The Task Force recommends that:

- NASA take the steps necessary to ensure greater awareness within the U.S. government of its value and that of its aerospace programs as an instrument of U.S. foreign policy.
- Cooperative agreements between NASA and foreign or international agencies be developed and maintained consistent with long-term foreign policy objectives as well as with scientific and technological objectives to achieve a greater degree of constancy and stability.

Document IV-17

Document title: ***Report of the Presidential Commission on the Space Shuttle Challenger Accident, Vol. I*** **(Washington, DC: U.S. Government Printing Office, June 6, 1986), pp. 164-77.**

The January 28, 1986, explosion of the Space Shuttle *Challenger* and the ensuing investigation invited comparison with the events that followed the launch-pad fire of the Apollo 204 spacecraft almost 19 years before that resulted in the deaths of three astronauts. During the earlier accident a politically strong administrator was at the helm of NASA; James E. Webb persuaded the White House to allow NASA to take the lead in the accident investigation. That investigation was largely technical, and it was sufficiently rigorous and critical to be seen as credible. It resulted primarily in engineering changes; what managerial changes Webb made as a result were surgical in nature, lest the agency's entire management corps be cast into confusion. In contrast, after the *Challenger* accident NASA's internal investigation took a back seat to the work of a White House-appointed commission, chaired by former Secretary of State William P. Rogers. NASA was unable to seize the initiative because, among other factors, its own top management was in disarray. The agency had been without a permanent administrator for two months, and Acting Administrator William Graham was an "outsider" not widely trusted within the agency. The report of the "Rogers Commission" was deliberate and thorough and, as this excerpt suggests, gave as much emphasis to the accident's managerial as to its technical origins.

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[164] **Pressures on the System**

With the 1982 completion of the orbital flight test series, NASA began a planned acceleration of the Space Shuttle launch schedule. One early plan contemplated an eventual rate of a mission a week, but realism forced several downward revisions. In 1985, NASA published a projection-calling for an annual rate of 24 flights by 1990. Long before the Challenger accident, however, it was becoming obvious that even the modified goal of two flights a month was overambitious.

In establishing the schedule, NASA had not provided adequate resources for its attainment. As a result, the capabilities of the system were strained by the modest nine-mission rate of 1985, and the evidence suggests that NASA would not have been able to accomplish the 15 flights scheduled for 1986. These are the major conclusions of a Commission examination of the pressures and problems attendant upon the accelerated launch schedule.

On the same day that the initial orbital tests concluded—July 4, 1982—President Reagan announced a national policy to set the direction of the U.S. space program during the following decade. As part of that policy, the President stated that:

"The United States Space Transportation System (STS) is the primary space launch systems for both national security and civil government missions."

Additionally, he said:

"The first priority of the STS program is to make the system fully operational and cost-effective in providing routine access to space."

From the inception of the Shuttle, NASA had been advertising a vehicle that would make space operations "routine and economical." The greater the annual number of flights, the greater the degree of routinization and economy, so heavy emphasis was placed on the schedule. However, the attempt to build up to 24 missions a year brought a number of difficulties, among them the compression of training schedules, the lack of spare parts, and the focusing of resources on near-term problems.

One effect of NASA's accelerated flight rate and the agency's determination to meet it was the dilution of human and material resources that could be applied to any particular flight.

The part of the system responsible for turning the mission requirements and objectives into flight software, flight trajectory information and crew training materials was struggling to keep up with the flight rate in late 1985, and forecasts showed it would be unable to meet its milestones for 1986. It was falling behind because its resources were strained to the limit, strained by the flight rate itself and by the constant changes it was forced to respond to within that accelerating schedule. Compounding the problem was the fact that NASA had difficulty evolving from its single-flight focus to a system that could efficiently support the projected flight rate. It was slow in developing a hardware maintenance plan for its reusable fleet and slow in developing the capabilities that would allow it to handle the higher volume of work and training associated with increased flight frequency.

[165] Pressures developed because of the need to meet customer commitments, which translated into a requirement to launch a certain number of flights per year and to launch them on time. Such considerations may occasionally have obscured engineering concerns. Managers may have forgotten—partly because of past success, partly because of their own well-nurtured image of the program—that the Shuttle was still in a research and development phase. In his testimony before a U.S. Senate Appropriations subcommittee on May 5, 1982, following the third flight of the Space Shuttle, James Beggs, then the NASA Administrator, expressed NASA's commitment

"The highest priority we have set for NASA is to complete development of the Shuttle and turn it into an operational system. Safety and reliability of flight and the control of operational costs are primary objectives as we move forward with the Shuttle program."

Sixteen months later, arguing in support of the Space Station, Mr. Beggs said, "We can start anytime.... There's no compelling reason [why] it has to be 1985 rather than '86 or '87. The point that we have made is that the Shuttle is now operational." The prevalent attitude in the program appeared to be that the Shuttle should be ready to emerge from the developmental stage, and managers we determined to prove it "operational."

Various aspects of the mission design and development process were directly affected by that determination. The sections that follow will discuss the pressures exerted on the system by the flight rate, the reluctance to relax the optimistic schedule, and the attempt to assume an operational status.

Planning of a Mission

The planning and preparation for a Space Shuttle flight require close coordination among those making the flight manifest, those designing the flight and the customers contracting NASA's services. The goals are to establish the manifest; define the objectives, constraints and capabilities of the mission; and translate those into hardware, software and flight procedures.

There are major program decision points in the development of every Shuttle flight. At each of these points, sometimes called freeze points, decisions are made that form the basis for further engineering and product development. The disciplines affected by these freeze points include integration hardware, engineering, crew timeline, flight design and crew training.

The first major freeze point is at launch minus 15 months. At that time the flight is officially defined: the launch date, Orbiter and major payloads are all specified, and initial design and engineering are begun based on this information.

The second major freeze point is at launch minus 7.7 months, the cargo integration hardware design. Orbiter vehicle configuration, flight design and software requirements are agreed to and specified. Further design and engineering can then proceed.

Another major freeze point is the flight planning and stowage review at launch minus five months. At that time, the crew activity timeline and the crew compartment configuration, which includes middeck payloads and payload specialist assignments, are established. Final design, engineering and training are based on these products.

Development of Flight Products

The "production process" begins by collecting all mission objectives, requirements and constraints specified by the payload and Space Shuttle communities at the milestones described above. That information is interpreted and assimilated as various groups generate products required for a Space Shuttle flight: trajectory data, consumables requirements, Orbiter flight software, Mission Control Center software and the crew activity plan, to name just a few.

Some of these activities can be done in parallel, but many are serial. Once a particular process has started, if a substantial change is made to the flight, not only does that process have to be started again, but the process that preceded it and supplied its date may also need to be repeated. If one group fails to meet its due date, the group that is next in the chain will start late. The delay then cascades through the system.

Were the elements of the system meeting their schedules? Although each group believed it had an adequate amount of time allotted to perform its function, the system as a whole was falling [166] behind. An assessment of the system's overall performance is best made by studying the process at the end of the production chain: crew training. Analysis of training schedules for previous flights and projected training schedules for flights in the spring and summer of 1986 reveals a clear trend: less and less time was going to be available for crew members to accomplish their required training....

The production system was disrupted by several factors including increased flight rate, lack of efficient production processing and manifest changes.

Changes in the Manifest

Each process in the production cycle is based on information agreed upon at one of the freeze points. If that information is later changed, the process may have to be repeated. The change could be a change in manifest or a change to the Orbiter hardware or software. The hardware and software changes in 1985 usually were mandatory changes; perhaps some of the manifest changes were not.

The changes in the manifest were caused by factors that fall into four general categories: hardware problems, customer requests, operational [167] constraints and external factors. The significant changes made in 1985 are shown in the accompanying table. The following examples illustrate that a single proposed change can have extensive impact, not because the change itself is particularly difficult to accommodate (though it may be), but because each change necessitates four or five other changes. The cumulative effect can be substantial....

When a change occurs, the program must choose a response and accept the consequences of that response. The options are usually either to maximize the benefit to the customer or to minimize the adverse impact on Space Shuttle operations. If the first option is selected, the consequences will include short-term and/or long-term effects....

1985 Changes in the Manifest

Hardware Problems

Tracking and Data Relay Satellite (canceled 51-E, added 61-M).

Synchronous Communication Satellite (added to 61-C).

Synchronous Communication Satellite (removed from 61-C).

OV-102 late delivery from Palmdale (changed to 51-G, 51-I, and 61-A).

Customer Requests

HS-376 (removed from 51-I).

G-Star (removed from 61-C).

Satellite Television Corporation-Direct Broadcast Satellite (removed from 61-E).

Westar (removed from 61-C).

Satellite Television Corporation-Direct Broadcast Satellite (removed from 61-H).

Electrophoresis Operations in Space (removed from 61-B).

Electrophoresis Operations in Space (removed from 61-H).

Hubble Space Telescope (swap with Earth Observation Mission).

Operational Constraints

No launch window for Skynet/Indian Satellite Combination (61-H).

Unacceptable structural loads for Tracking and Data Relay Satellite/Indian Satellite (61-H).

Landing weight above allowable limits for each of the following missions: 61-A, 61-E, 71-A, 61-K.

External Factors

Late addition of Senator Jake Garn (R-Utah) (51-D).

Late addition of Representative Bill Nelson (D-Florida) (61-C).

Late addition of Physical Vapor Transport Organic Solid experiment (51-I).

[168] Operational constraints (for example, a constraint on the total cargo weight) are imposed to ensure that the combination of payloads does not exceed the Orbiter's capabilities. An example involving the Earth Observation Mission Spacelab flight is presented in the NASA Mission Planning and Operations Team Report in Appendix J. That case illustrates that changes resulting from a single instance of a weight constraint violation can cascade through the entire schedule.

External factors have been the cause of a number of changes in the manifest as well. The changes discussed above involve major payloads, but changes to other payloads or to payload specialists can create problems as well. One small change does not come alone; it generates several others. A payload specialist was added to mission 61-C only two months before its scheduled lift off. Because there were already seven crew members assigned to the flight, one had to be removed. The Hughes payload specialist was moved from 61-C to 51-L just three months before 51-L was scheduled to launch. His experiments were also added to 51-L. Two middeck experiments were deleted from 51-L as a result, and the deleted experiments would have reappeared on later flights. [169] Again, a "single" late change affected at least two flights very late in the planning and preparation cycles.

The effects of such changes in terms of budget, cost and manpower can be significant. In some cases, the allocation of additional resources allows the change to be accommodated with little or no impact to the overall schedule. In those cases, steps that need to be re-done can still be accomplished before their deadlines. The amount of additional resources required depends, of course, on the magnitude of the change and when the change occurs: early changes, those before the cargo integration review, have only a minimal impact; changes at launch minus five months (two months after the cargo integration review) can carry a major impact, increasing the required resources by approximately 30 percent. In the missions from 41-C to 51-L, only 60 percent of the major changes occurred before the cargo integration review. More than 20 percent occurred after launch minus five months and caused disruptive budget and manpower impacts.

Engineering flight products are generated under a contract that allows for increased expenditures to meet occasional high workloads. [170] Even with this built-in flexibility, however, the requested changes occasionally saturate facilities and personnel capabilities. The strain on resources can be tremendous. For short periods of two to three months in mid-1985 and early 1986, facilities and personnel were being required to perform at roughly twice the budgeted flight rate.

If a change occurs late enough, it will have an impact on the serial processes. In these cases, additional resources will not alleviate the problem, and the effect of the change is absorbed by all downstream processes, and ultimately by the last element in the chain. In the case of the flight design and software reconfiguration process, that last element is crew training. In January, 1986, the forecasts indicated that crews on flights after 51-L would have significantly less time than desired to train for their flights....

"Operational" Capabilities

For a long time during Shuttle development, the program focused on a single flight, the first Space Shuttle mission. When the program became "operational," flights came more frequently, and the same resources that had been applied to one flight had to be applied to several flights concurrently. Accomplishing the more pressing immediate requirements diverted attention from what was happening to the system as a whole. That appears to be one of the many telling differences between a "research and development" program and an "operational program." Some of the differences are philosophical, some are attitudinal and some are practical.

Elements within the Shuttle program tried to adapt their philosophy, their attitude and their requirements to the "operational era." But that era came suddenly, and in some cases, there had not been enough preparation for what "operational" might entail. For example, routine and regular post-flight maintenance and inspections are critical in an operational program; spare parts are critical to flight readiness in an operational fleet; and the software tools and training facilities developed during a test program may not be suitable for the high volume of work required in an operational environment. In many respects, the system was not prepared to meet an "operational" schedule.

As the Space Shuttle system matured, with numerous changes and compromises, a comprehensive set of requirements was developed to ensure the success of a mission. What evolved was a system in which the preflight processing, flight planning, flight control and flight training were accomplished with extreme care applied to every detail. This process checked and rechecked everything, and though it was both labor- and time-intensive, it was appropriate and necessary for a system still in the developmental phase. This process, however, was not capable of meeting the flight rate goals.

After the first series of flights, the system developed plans to accomplish what was required to support the fight rate. The challenge was to streamline the processes through automation, standardization, and centralized management, and to convert from the developmental phase to the mature system without a compromise in quality. It required that experts carefully analyze their areas to determine what could be standardized and automated, then take the time to do it.

But the increasing flight rate had priority—quality products had to be ready on time. Further, schedules and budgets for developing the needed facility improvements were not adequate. Only the time and resources left after supporting the flight schedule could be directed toward efforts to streamline and standardize. In 1985, NASA was attempting to develop the capabilities of a production system. But it was forced to do that while responding—with the same personnel—to a higher flight rate.

At the same time the flight rate was increasing, a variety of factors reduced the number of skilled personnel available to deal with it. Theses included retirements, hiring freezes, transfers to other programs like the Space Station and transitioning to a single contractor for operations support.

[171] The flight rate did not appear to be based on assessment of available resources and capabilities and was not reduced to accommodate the capacity of the work force. For example, on January 1, 1986, a new contract took effect at Johnson that consolidated the entire contractor work force under a single company. This transition was another disturbance at a time when the work force needed to be performing at full capacity to meet the 1986 flight rate. In some important areas, a significant fraction of workers elected not to change contractors. This reduced the work force and its capabilities, and necessitated intensive training programs to qualify the new personnel. According to projections, the work force would not have been back to full capacity until the summer of 1986. This drain on a critical part of the system came just as NASA was beginning the most challenging phase of its flight schedule.

Similarly, at Kennedy the capabilities of the Shuttle processing and facilities support work force became increasingly strained as the Orbiter turnaround time decreased to accommodate the accelerated launch schedule. This factor has resulted in overtime percentages of almost 28 percent in some directorates. Numerous contract employees have worked 72 hours per week or longer and frequent 12-hours shifts. The potential implications of such overtime for safety were made apparent during the attempted launch of mission 61-C on January 6, 1986, when fatigue and shiftwork were cited as major contributing factors to a serious incident involving a liquid oxygen depletion that occurred less than five minutes before scheduled lift off....

Responding to Challenges and Changes

Another obstacle in the path toward accommodation of a higher flight rate is NASA's legendary "can-do" attitude. The attitude that enabled the agency to put men on the moon and to build the Space Shuttle will not allow it to pass up an exciting challenge—even though accepting the challenge may drain resources from the more mundane (but necessary) aspects of the program.

A recent example is NASA's decision to perform a spectacular retrieval of two communications satellites whose upper-stage motors had failed to raise them to the proper geosynchronous orbit. NASA itself then proposed to the insurance companies who owned the failed satellites that the agency design a mission to rendezvous with them in turn and that an astronaut in a jet backpack fly over to escort the satellites into the Shuttle's payload bay for a return to Earth.

The mission generated considerable excitement within NASA and required a substantial effort to develop the necessary techniques, hardware and procedures. The mission was conceived, created, designed and accomplished within 10 months. The result, mission 51-A (November, 1984), was a resounding success, as both failed satellites were successfully returned to Earth. The retrieval mission vividly demonstrated the service that astronauts and the Space Shuttle can perform.

Ten months after the first retrieval mission, NASA launched a mission to repair another communications satellite that had failed in low-Earth orbit. Again, the mission was developed and executed on relatively short notice and was resoundingly successful for both NASA and the satellite insurance industry.

The satellite retrieval missions were not isolated occurrences. Extraordinary efforts on NASA's part in developing and accomplishing missions will, and should, continue, but such efforts will be a substantial additional drain on resources. NASA cannot both accept the relatively spur-of-[172] the-moment missions that its "can-do" attitude tends to generate and also maintain the planning and scheduling discipline required to operate as a "space truck" on a routine and cost-effective basis. As the flight rate increases, the cost in resources and the accompanying impact on future operations must be considered when infrequent but extraordinary efforts are undertaken. The system is still not sufficiently developed as a "production line" process in terms of planning or implementation procedures. It cannot routinely or even periodically accept major disruptions without considerable cost. NASA's attitude historically has reflected the position that "We can do anything," and while that may essentially be true, NASA's optimism must be tempered by the realization that it cannot do everything.

NASA has always taken a positive approach to problem solving and has not evolved to the point where its officials are willing to say they no longer have the resources to respond to proposed changes....

[173] It is important to determine how many flights can be accommodated, and accommodated safely. NASA must establish a realistic level of expectation, then approach it carefully. Mission schedules should be based on a realistic assessment of what NASA can do safely and well, not on what is possible with maximum effort. The ground rules must be established firmly, and then enforced.

The attitude is important, and the word operational can mislead. "Operational" should not imply any less commitment to quality or safety, nor a dilution of resources. The attitude should be, "We are going to fly high risk flights this year; every one is going to be a challenge, and every one is going to involve some risk, so we had better be careful in our approach to each."...

[176] **Findings**

1. The capabilities of the system were stretched to the limit to support the flight rate in winter 1985/1986. Projections into the spring and summer of 1986 showed a clear trend; the system, as it existed, would have been unable to deliver crew training software for scheduled flights by the designated dates. The result would have been an unacceptable compression of the time available for the crews to accomplish their required training.

2. Spare parts are in critically short supply. The Shuttle program made a conscious decision to postpone spare parts procurements in favor of budget items of perceived higher priority. Lack of spare parts would likely have limited flight operations in 1986.

3. Stated manifesting policies are not enforced. Numerous late manifest changes (after the cargo integration review) have been made to both major payloads and minor payloads throughout the Shuttle program.

- Late changes to major payloads or program requirements can require extensive resources (money, manpower, facilities) to implement.
- If many late changes to "minor" payloads occur, resources are quickly absorbed.
- Payload specialists frequently were added to a flight well after announced deadlines.
- Late changes to a mission adversely affect the training and development of procedures for subsequent missions.

[177] 4. The scheduled flight rate did not accurately reflect the capabilities and resources.

- The flight rate was not reduced to accommodate periods of adjustment in the capacity of the work force. There was no margin in the system to accommodate unforeseen hardware problems.
- Resources were primarily directed toward supporting the flights and thus not enough were available to improve and expand facilities needed to support a higher flight rate.

5. Training simulators may be the limiting factor on the flight rate: the two current simulators cannot train crews for more than 12-15 flights per year.

6. When flights come in rapid succession, current requirements do not ensure that critical anomalies occurring during one flight are identified and addressed appropriately before the next flight.

Document IV-18

Document title: Samuel C. Phillips, NASA Management Study Group, "Recommendations to the Administrator," December 30, 1986.

Source: NASA Historical Reference Collection, NASA History Office, NASA Headquarters, Washington, D.C.

In the wake of the *Challenger* accident, former NASA Administrator James C. Fletcher was asked by President Reagan to return to the agency. One of Fletcher's early actions was to seek the advice of the National Academy of Public Administration on the management issues facing him. The academy's response was to organize a NASA Management Study Group, headed by retired General Samuel C. Phillips, who had been program manager for Apollo. The group's final report provided an overview of NASA's management problems in the post-*Challenger*, Space Station era.

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Summary Report of the NASA Management Study Group Recommendations

I. INTRODUCTION

The NASA Management Study Group (NMSG) was established under the auspices of the National Academy of Public Administration at the request of the Administrator of NASA to assess NASA's Management practices and to evaluate the effectiveness of the NASA organization. The NMSG addresses first the organization and management of the space station program, then the restructuring of the space shuttle program, and finally NASA's overall organization and management.

Recommendations of the NMSG on the space station program were made in the form of oral briefings to the Administrator and other officials of NASA on June 26, 1986, and have subsequently been largely implemented. With respect to the space shuttle program the NMSG contributed to and reviewed the study led by Astronaut Robert Crippen and participated in the discussions that led to the Administrator's decisions announced on November 5, 1986, with which the NMSG has concurred.

This report summarizes the conclusions and recommendations of the NMSG on the overall management and organization of NASA. Detailed findings and draft recommendations were presented and discussed on several occasions during the course of the study in oral briefings to the Administrator and to the Advisory Panel of the National Academy of Public Administration. A presentation was made to the entire team of NASA top headquarters officials and center directors at an all day meeting on November 25, 1986. A final report, in the form of a revised oral briefing taking account of the comments of the Advisory Panel and the NASA officials after the November 25 meeting, was presented to Administrator and Deputy Administrator on December 16, 1986.

[2] II. GENERAL OBSERVATIONS

The NMSG study has concentrated on identifying issues in need of special attention by NASA management at this time. As a result, our recommendations focus on areas where changes or improvement may be required.

We must emphasize, at the outset, therefore, that a principal finding of our study is that NASA is fundamentally a sound institution, with many outstanding people with strong dedication to the success of NASA and its programs. We also recognize that many positive steps have been taken in recent months to strengthen the organization, management, and practices of NASA, and that some NMSG recommendations were adopted during the course of our study. The conclusions and recommendations set forth below should be viewed in this context.

The NMSG recognizes that NASA management is conditioned to a significant degree by factors in the external environment over which NASA has only limited control. NASA must conform to Administration policies, budgetary restrictions, Congressional guidance, and the increasingly complex web of legal and regulatory constraints affecting procurement, personnel, and other areas. As a result of the Challenger accident, NASA faces increased critical scrutiny by Congress and the media, a long hiatus in space flights, and some unrealistic public expectations of risk-free space flight. On the other hand, NASA and its program have the President's personal interest and support, and there is, we believe, strong public and Congressional support as well.

In this situation, NASA has the challenge of coping with its external environment and managing its affairs in a way that earns the respect and continued support of the Administration, Congress, and the public. To reestablish NASA's leadership [3] position in space and aeronautics, management excellence is as essential as technical excellence. Our recommendations are intended as suggestions to help NASA achieve the level of excellence it must have.

III. PRINCIPAL RECOMMENDATIONS

The principal recommendations of the NMSG can be summarized as follow:

1. Establish strong headquarters program direction for each major NASA program, with clear assignment of responsibilities to the NASA centers involved.
2. Improve the discipline and responsiveness to problems of the program management system.
3. Place shuttle and space station programs under a single Associate Administrator when the Administrator is satisfied that recovery of the shuttle will not thereby be compromised.
4. Increase management emphasis on space flight operations.
5. Place special management emphasis on establishing NASA world-class leadership in advanced technology in selected areas of both space and aeronautical technology.
6. Establish a formal planning process within NASA to enunciate long-range goals and lay out program, institutional, and financial plans for meeting them.
7. Strengthen agency-wide leadership in developing and managing people, facilities, equipment, and other institutional resources.

[4] 8. Improve management of NASA's external relations.

9. Strengthen the Office of the Administrator and ease the workload of the Administrator and Deputy Administrator.

These and other NMSG recommendations are discussed briefly in the following sections for each of the areas covered by the NMSG study.

IV. PROGRAM MANAGEMENT

Effective management of its technical program is NASA's central task. Five of the principal NMSG recommendations and many subsidiary recommendations are in this area.

1. **Establish strong headquarters program direction for each major NASA program, with clear assignment of responsibilities to the NASA center involved.**

a. Large multi-center spaceflight programs should be managed by a strong program director at headquarters supported by a competent program office in the Washington area. The functions of the headquarters program office should include systems engineering (a support contractor may be needed); program planning and control; management of operations and interfaces with users; safety, reliability, and quality assurance;

and other functions as appropriate. Program managers at each center should have clearly defined responsibilities and accountability to the headquarters program director. The NMSG has concurred in the actions now being taken to structure the shuttle and space station programs in this way. The NMSG also believes that the Technical Management Information System (TMIS) proposed for the space station program should be initiated but should be subject to periodic [5] review by non-advocates and outside experts to ensure that the expected utility is being achieved.

b. Single center spaceflight programs or projects should also have a program director at headquarters with the overall program control functions of establishing requirements, reviewing progress, and approving changes as necessary. A central program control staff at the Program AA level could support the directors of several smaller programs. The program or project manager at the center should be responsible for planning and implementing the program (including systems engineering), for keeping the program director regularly informed of status and problems, and for requesting his approval of major changes that may be necessary.

c. NASA should avoid organizing major programs so that large tasks are assigned to more than one center unless technical demands or the scale of the program clearly require substantial contribution from more than one center.

d. A highly qualified independent office of safety, reliability, and quality assurance is an essential requirement for assuring safety and success in NASA programs. The NMSG has reviewed the goals, organization, priorities, and general plans of the new office recently established in NASA and agrees with the actions already taken and now planned.

e. NASA Headquarters and each center should assess their procurement practices to seek to minimize the long lead times in placing contracts and to assure that proper emphasis is placed on contract structure, contractor selection, and contract administration.

[6] 2. **Improving the discipline and responsiveness of the program management system.**

a. Reinstitute the former system of Program Approval Documents (PAD's) as the basic agreement between the Administrator and the Program Associate Administrator responsible for the program. The PAD should contain the official statement of the program objectives and scope, how the program is to be performed, the responsibilities of the participating organizations, the total resources required (dollars, people, facilities and support from other organizations), and cost and schedule baselines against which progress can be measured. Program control documents at successive lower levels of management should be integrated into a system consistent with and supporting the PADS.

b. Revitalize regular status reviews at each successive level of management at which progress is measured against the approved baselines, current and potential problems are fully discussed and actions assigned. The Administrator or Deputy Administrator should conduct periodic reviews of all major NASA programs.

c. Strengthen the agency's independent cost estimating and program assessment capabilities at headquarters and at the centers.

3. **Place shuttle and space station programs under a single Associate Administrator when the Administrator is satisfied that recovery of the shuttle will not thereby be compromised.** Although now in very different stages of development, the shuttle and space station programs should be unified to ensure proper attention to compatibility of space station design and operational planning with the shuttle and its capabilities, [7] operational availability, and requirements for logistic support. Nevertheless, the programs should not be combined until it is clear that the NASA's top priority task of returning the shuttle to flight status will not thereby be adversely affected. Until the programs are combined under one AA, the offices of Space Station and Space Flight should jointly prepare plans for the Administrator's approval which clearly define their responsibilities and relationships.

4. **Increase management emphasis on spaceflight operations.** NASA must accept that it will be responsible for spaceflight operations for the foreseeable future - shuttle, space station, man-tended and free-flying spacecraft, deep space probes, etc. The present structure of organization and management does not assure adequate attention to operations requirements in system design or in the planning and conduct of operations and logistic support in the era of frequent shuttle flights and long-term operations of the space station. A better delineation between development and operations activities is needed even before the shuttle or space station become operational. It is also important that steps be taken to accommodate users more efficiently without compromising safety. At the same time, the shuttle recovery program must not be placed at risk. Therefore, NASA should:

a. Strengthen management of operations in the space shuttle program at headquarters and the NASA centers. Steps to do this are now under way.

b. Ensure responsiveness to operational and user requirements in the design and development of the space station. The Offices of Space Station (OSS), Space Science and Applications, and Aeronautics and Space Technology should jointly prepare plans for the Administrator's approval which clearly define their responsibilities and relationships. OSS should ensure [8] that its organization and procedures provide adequate linkages with all major user constituencies.

c. Establish a new Associate Administrator for Operations to develop a comprehensive plan for managing NASA spaceflight operations, to be implemented when shuttle recovery is complete. Initial priority should be given to planning for the future management of manned, mantended, and related operations. The present Offices of Space Tracking and Data Systems should become a division in the new Office of Spaceflight Operations. The NMSG anticipates that at some point in the future, the Kennedy Space Center would also be placed under the Office of Spaceflight Operations.

5. **Place special management emphasis on establishing NASA world-class leadership in advanced technology in selected areas of both space and aeronautical technology.** The NMSG believes that NASA's efforts to develop advanced technologies beyond the requirements of current spaceflight programs, on which the U.S. future in space and aeronautics will depend, need more emphasis and a clearer sense of direction. Specifically, NASA should:

a. Strengthen capabilities for advanced research and technology development at all NASA centers.

b. Limit spaceflight program management activities at NASA OAST research centers. This should permit a stronger focus on advanced research and technology.

c. Seek to establish stronger linkages between the NASA research centers and industry in space technology, comparable to those that now exist in aeronautics.

[9] V. PLANNING

6. **Establish a formal planning process within NASA to enunciate long-range goals and lay out program, institutional, and financial plans for meeting them.** NMSG believes that a formal iterative planning process that involves direct participation of the entire NASA line organization at headquarters and the center would materially assist NASA by giving a clearer sense of direction and better focus to its programs.

a. A biennial planning process should be instituted to develop detailed program, institutional, and financial plans for the next five years and skeletal plans for the ten years beyond.

b. The plans should be developed by the line organization, based on goals and guidelines enunciated by the Administrator after taking account of the views and recommendations of the NASA program offices, congressional reports, scientific and other advisory groups, and other constituencies.

c. The present Strategic Planning Council should be retained and its role broadened to include an annual evaluation of progress against plans.

d. A small planning support staff should be established in a new Policy and Planning Support Office reporting to the Administrator, to analyze and integrate planning within the agency and to publish and update agency plans. (See also VII-9-c.)

[10] VI. INSTITUTIONAL MANAGEMENT

7. **Strengthen agency-wide leadership in developing and managing people, facilities, equipment, and other institutional resources.** The NMSG believes that more attention needs to be given at headquarters and the centers to improving the management of NASA as an institution, both to make current agency operations more efficient and to assure the future strength of NASA capabilities. The NMSG recommends that NASA:

a. Appoint an Associate Deputy Administrator-Institution to provide a focus on institutional management in the Office of the Administrator. This official would assist, and when appropriate act for the Administrator and Deputy Administrator on institutional matters generally, including determination of requirements and distribution of resources for manpower, facilities, and institutional funding.

b. Strengthen the institutional management capabilities of the Program Associate Administrators, who should continue to be responsible for supervising NASA field centers as at present. Each Program Associate Administrator having supervision of a field center must assure the center's responsiveness to the requirements of programs assigned by other Associate Administrators.

c. Establish institutional planning as an integral part of the NASA planning process, to include planning for personnel, facilities, major equipment and support service contractor requirements and for the evolution of the assigned roles and missions of NASA Centers. A small staff focused on institutional planning should be included in the new Policy and Planning Support office recommended below (VII-9-c).

[11] d. Place a new special management emphasis on human resources in NASA to enhance efforts to acquire, retain, and make full utilization of the best possible people to conduct and manage NASA's work. Where necessary to meet its special needs, NASA should seek administrative or legislative relief from general government requirements that impede effective human resources management.

VII. EXECUTIVE MANAGEMENT

8. **Improve management of NASA's external relations.**

a. Give special management attention to ensuring that NASA:

(1) Keeps Congress informed on a timely basis of matters of importance or special interest.

(2) Is effectively represented in dealings with other agencies, other governments, and industry.

(3) Maintains the NASA tradition of openness in its relations with the media and the public.

b. Consolidate under the Associate Administrator for External Relations the functions of public, international, and industry affairs, with either de facto or actual responsibility for legislative affairs.

c. Reaffirm to all headquarters offices and field centers the requirement for consistent agency policies and actions in external affairs under the functional management leadership of the headquarters staff offices.

[12] 9. **Strengthen the Office of the Administrator and ease the workload of the Administrator and Deputy Administrator.** The NMSG believes that these needs can best be addressed by appointing two new senior officials within the Office of the Administrator and the establishment of a small policy and planning support staff unit. Specifically, NASA should:

a. Appoint an Associate Deputy Administrator-Policy to assist, and where appropriate act for the Administrator, on policy, external affairs, and related matters. The Administrator continually faces problems in the policy and external affairs areas that are growing in number and complexity. Coping with these problems now requires major personal involvements of the Administrator, creating the risks of insufficient attention to policy matters, missed opportunities for leadership, and diversion from other important responsibilities. The Associate Deputy Administrator-Policy would share the Administrator's and Deputy Administrator's workload and help ensure effective use and participation of NASA staff and program offices in policy matters and external affairs.

b. Appoint an Associate Deputy Administrator-Institution to assist, and where appropriate act for the Administrator or Deputy Administrator in the management of NASA as an institution (IV-7-a).

c. Establish a small Policy and Planning Support Staff for policy analysis and to support the program and institutional planning processes. This staff would provide a resource for the Office of the Administrator to perform or coordinate selected policy studies and analysis as assigned, and to assist in the review of studies and analysis done elsewhere in the agency. It [13] would also provide support for the program and institutional planning processes as previously recommended.

Document IV-19

Document title: NASA, "The Hubble Space Telescope Optical Systems Failure Report," November 1990, pp. iii-v, 9-1 to 9-4, 10-1 to 10-4.

Source: NASA Historical Reference Collection, NASA History Office, NASA Headquarters, Washington, D.C.

The Hubble Space Telescope was launched in May 1990 with an aberration in its primary mirror that made the telescope unable to carry out significant aspects of its planned observations. The fault in the mirror was introduced during its manufacture in the early 1980s and not detected in the testing program that preceded assembly and launch of the telescope. NASA in July 1990 established a Board of Investigation to identify reasons for the fault in the Hubble mirror and for the failure to detect the fault prior to launch. The board was chaired by Jet Propulsion Laboratory Director Lew Allen.

These excerpts from the board's report reflect the shortfalls in NASA technical management and quality assurance that contributed, along with the performance of the mirror manufacturer Perkin-Elmer, to the problems with the Hubble mirror.

[iii] EXECUTIVE SUMMARY

The Hubble Space Telescope (HST) was launched aboard the Space Shuttle Discovery on April 24, 1990. During checkout on orbit, it was discovered that the telescope could not be properly focused because of a flaw in the optics. The HST Project Manager announced this failure on June 21, 1990. Both of the high-resolution imaging cameras (the Wide Field/Planetary Camera and the Faint Object Camera) showed the same characteristic distortion, called spherical aberration, that must have originated in the primary mirror, the secondary mirror, or both.

The National Aeronautics and Space Administration (NASA) Associate Administrator for the Office of Space Science and Applications then formed the Hubble Space Telescope Optical Systems Board of Investigation on July 2, 1990, to determine the cause of the flaw in the telescope, how it occurred, and why it was not detected before launch. The Board conducted its investigation to include interviews with personnel involved in the fabrication and test of the telescope, review of documentation, and analysis and test of the equipment used in the fabrication of the telescope's mirrors. The information in this report is based exclusively on the analysis and tests requested by the Board, the testimony given to the Board, and the documentation found during this investigation.

Continued analysis of images transmitted from the telescope indicated that most, if not all, of the problem lies in the primary mirror. The Board's investigation of the manufacture of the mirror provéd that the mirror was made in the wrong shape, being too much flattened away from the mirror's center (a 0.4-wave rms wavefront error at 632.8 nm). The error is ten times larger than the specific tolerance.

The primary mirror is a disc of glass 2.4 m in diameter, whose polished front surface is coated with a very thin layer of aluminum. When glass is polished, small amounts of material are worn away, so by selectively polishing different parts of a mirror, the shape is altered. During the manufacture of all telescope mirrors there are many repetitive cycles in which the surface is tested by reflecting light from it; the surface is then selectively polished to correct any errors in its shape. The error in the HST's mirror occurred because the optical test used in this process was not set up correctly; thus the surface was polished into the wrong shape.

The primary mirror was manufactured by the Perkin-Elmer Corporation, now Hughes Danbury Optical Systems, Inc., which was the contractor for the Optical Telescope Assembly. The critical optics used as a template in shaping the mirror, the reflective null corrector (RNC), consisted of two small mirrors and a lens. The [iv] RNC was designed and built by the Perkin-Elmer Corporation for the HST Project. This unit had been preserved by the manufacturer exactly as it was during the manufacture of the mirror. When the Board measured the RNC, the lens was incorrectly spaced from the mirrors. Calculations of the effect of such displacement on the primary mirror show that the measured amount, 1.3 mm, accounts in detail for the amount and character of the observed image blurring.

No verification of the reflective null corrector's dimensions was carried out by Perkin-Elmer after the original assembly. There were, however, clear indications of the problem from auxiliary optical tests made at the time, the results of which have been studied by the Board. A special optical unit called an inverse null corrector, designed to mimic the reflection from a perfect primary mirror, was built and used to align the apparatus; when so used, it clearly showed the error in the reflective null corrector. A second null corrector, made only with lenses, was used to measure the vertex radius of the finished primary mirror. It, too, clearly showed the error in the primary mirror. Both indicators of error were discounted at the time as being themselves flawed.

The Perkin-Elmer plan for fabricating the primary mirror placed complete reliance on the reflective null corrector as the only test to be used in both manufacturing and verifying the mirror's surface with the required precision. NASA understood and accepted this plan. This methodology should have alerted NASA management to the fragility of the process and the possibility of gross error, that is, a mistake in the process, and the need for continued care and consideration of independent measurements.

The design of the telescope and the measuring instruments was performed well by skilled optical scientists. However, the fabrication was the responsibility of the Optical Operations Division at the Perkin-Elmer Corporation (P-E), which was insulated from review or technical supervision. The P-E design scientists, management, and Technical Advisory Group, as well as NASA management and NASA review activities, all failed to follow the fabrication process with reasonable diligence and, according to testimony, were unaware that discrepant data existed, although the data were of concern to some members of P-E's Optical Operations Division. Reliance on a single test method was a process which was clearly vulnerable to simple error. Such errors had been seen in other telescope programs, yet no independent tests were planned, although some simple tests to protect against major error were considered and rejected. During the critical time period, there was great concern about cost and schedule, which further inhibited consideration of independent tests.

The most unfortunate aspect of this HST optical system failure, however, is that the data revealing these errors were available from time to time in the fabrication [v] process, but were not recognized and fully investigated at the time. Reviews were inadequate, both internally and externally, and the engineers and scientists who were qualified to analyze the test data did not do so in sufficient detail. Competitive, organizational, cost, and schedule pressures were all factors in limiting full exposure of all the test information to qualified reviewers....

[9-1] CHAPTER IX

WHY THE ERROR WAS NOT DETECTED PRIOR TO FLIGHT

The explanations for why the HST error was not detected before launch can be separated into two categories: factual and judgmental. Based on the test plan that was in place at the time of the fabrication of the HST mirrors, the factual issues presented in this Chapter were events that should have warned the Project personnel of the existence of a problem. The judgmental issues that follow are conclusions based on the Board's own expertise.

A. FACTUAL STATEMENTS

1. Complete reliance was placed on the reflective null corrector (RNC) to determine the shape of the primary mirror. It was determined that the RNC would be certified only by accurate measurement of the elements and the spacings. Although test philosophy placed great emphasis on "certification" of the RNC, the Board could not find documentation that the RNC was certified. In spite of the total reliance on the RNC, no independent measurements were made of the optical-element spacings of the RNC to verify the values. Although the RNC was designed so that spacings could be rechecked without disassembly, the actual implementation did not permit such measurements, and no remeasurement of spacings was made after initial assembly.

2. The erroneous measurement of the spacing of the field lens of the RNC led to the need to install spacers to increase the separation of the field lens from the lower mirror. The bolts securing the field-lens basket were not staked, suggesting a lack of quality surveillance, since securing bolts was a common and easily observable inspection to conduct. These anomalies should have led to a Material Review Board (MRB) approval document and a thorough consideration of the cause. Although the NASA representative recalls approving such an MRB, no documentation was found.

3. After the RNC was assembled in the laboratory, an INC was set up below the RNC. The INC was intended to simulate a perfect mirror below the RNC so that any errors in the null corrector could be detected. The interferograms taken when using the INC to align the RNC/CORI indicated a spherical aberration pattern (see Figure D-3). The full RNC/CORI assembly was then moved to the top of the optical telescope assembly test chamber, and each time the primary mirror was tested the INC was used to check the alignment of the setup. As before, the same spherical aberration distortion was evident in the fringes. These aberration fringes [9-2] could not be aligned out and were incorrectly attributed to the spacing errors in the lens system of the INC. Perkin-Elmer's Optical Operation Division believed that the INC was not reliable when, in fact, it was quite accurate enough to detect the gross error, and indeed did so.

4. The vertex radius measurement taken by the refractive null corrector (RvNC) indicated the presence of spherical aberration (see Figure D-2). This information was dismissed, as it was in the case for the INC, because the RvNC was believed to be less precise than the RNC and therefore not reliable. It has been determined that the RvNC was easily accurate enough to detect the spherical aberration the existed, and its reliability should not have been discounted.

5. There were two other occasions when a careful analysis of the data might have revealed the problem:

a. The primary mirror was ground and polished to an approximate shape, about 1 wavelength rms, using the RNC for the test. This took place at Perkin-Elmer's facility in Wilton, Connecticut. The mirror was then transferred to P-E's Danbury facility, where the RNC was the test instrument for final polishing. At the time of transfer, the interferograms obtained with the RvNC were compared with those obtained from the RNC, and the discrepancy could have been noted. However, the data and the circumstances of transfer are unclear, and the requirements for transfer appeared to be adequately met; therefore no concern was noted.

b. After the assembly of the OTA, tests were performed to assure proper focus position. Those tests were made with a 0.36-mn telescope (subaperture test), and careful analysis of the data might have revealed the problem. However, the data were complicated by gravity sag because the OTA was mounted horizontally, and only the focus position was verified.

6. A range of feasible tests to verify the shape of the primary mirror were considered, but not carried out. Finally, no end-to-end tests were planned or implemented to verify the performance of the OTA.

B. JUDGMENTAL STATEMENTS

The following judgements are offered with the recognition that there were many distraction and crises during this period-cost, schedule, threat of cancellation, mirror contamination, possibility of mirror distortion caused by [9-3] mount, etc. Nevertheless, the flaw occurred and, as can now be seen, these are factors that bear on that occurrence.

1. The proposal of P-E, accepted by NASA, to rely entirely on the RNC should have alerted knowledgeable people in P-E and NASA that special attention was required to certify the RNC; to the need for independent validation of the RNC and/or the primary mirror; and to the need to examine and review the test data for any indications of inconsistency. A project test plan that considered the various measurements, the possibilities of error in each, and the feasibility of independent checks should have been prepared by the implementing organization and externally reviewed.

2. The conclusion by P-E, accepted by NASA, that the RNC was the only device that would yield an accuracy of 0.01 wave rms at 632.8 nm led P-E to fail to consider any independent measurement which would yield less accuracy. In fact, such independent data were obtained incidental to other measurements and were rationalized away due to this mindset.

3. The HST development program was complex and challenging and there were many issues demanding management attention; the primary mirror was only one of these. Although the telescope was recognized as a particular challenge, with a primary mirror requiring unprecedented performance, there was a surprising lack of participation by optical experts with experience in the manufacture of large telescopes during the fabrication phase. The NASA Project management did not have the necessary expertise to critically monitor the optical activities of the program and to probe deeply enough into the adequacy and competence of the review process that was established to guard against technical errors. The record of reviews reveals no sensitively to in-process data and no questioning of the test method.

4. The NASA Scientific Advisory Group did not have the depth of experience and skill to critically monitor the fabrication and test results of a large aspheric mirror. However, this Group should have recognized the criticality of the figure of the primary mirror and the fragility of the metrology approach, and these concerns should have impelled them to penetrate the process and ask for validation.

5. A highly competitive environment existed between Perkin-Elmer and the Eastman Kodak subcontractor. Although the manufacturing process and the method of measurement for the backup primary mirror were reviewed and approved by P-E, there was limited additional technical exchange of experience. NASA did not utilize the opportunity offered by this directed subcontract to validate, and gain confidence in, the P-E approach to the primary mirror manufacture.

[9-4] 6. Perkin-Elmer line management did not review or supervise their Optical Operations Division adequately. In fact, the management structure provided a strong block against communication between the people actually doing the job and higher level experts both within and outside of P-E.

7. The P-E Technical Advisory Group did not probe at all deeply into the optical manufacturing processes and, although they recognized the fragility of the measuring approach, they did not adequately assert their concerns or follow up with data reviews. This is particularly surprising since the members were aware of the history of manufacture of other Ritchey-Chretien telescopes, where spherical aberration was known to be a common problem.

8. The most capable optical scientists at P-E were involved closely with the production of the 1.5-m demonstration mirror and the design of the HST mirror and the test apparatus. However, fabrication of the HST mirror was the responsibility of the Optical Operations Division of P-E, which did not include optical design scientists and which did not use the skills external to the Division which were available at Perkin-Elmer.

9. The Optical Operations Division at P-E operated in a "closed-door" environment which permitted discrepant data to be discounted without review. During the testimony, it was indicated that some technical personnel in the Optical Operations Division were deeply concerned at the time that the discrepant optical data might indicate a flaw. There are no indications that these concerns were formally expressed outside this Division.

10. The quality assurance people at P-E, NASA, and DCAS (Defense Contract Administration Services, now Defense Contract Management Command) were not optical experts and, therefore, were not able to distinguish the presence of inconsistent data results from the optical tests. The DCAS people concentrated mainly on safety issues.

11. The basic product assurance requirements and formal review processes were procedurally adequate to raise critical issues in most safety, material, and handling matters, but not in optical matters.

12. The inability of P-E to provide the Board with vital archival data on the design and manufacture of the primary mirror is an indication of inadequate documentation practices, which hampered the Board in determining the source of the primary mirror error.

[10-1] CHAPTER X

LESSONS LEARNED

A. IDENTIFY AND MITIGATE RISK

The Project Manager must make a deliberate effort to identify those aspects of the project where there is a risk of error with serious consequences for the mission. Upon recognizing the risks the manager must consider those actions which mitigate that risk.

[10-2] In this case, the primary mirror fabrication task was identified as particularly challenging due to the stringent performance requirements. The contractor clearly specified in the proposal that total reliance would be placed on a single test instrument and that no optical performance tests would be made at higher levels of assembly. Therefore, OTA performance would be determined by component tests and great care in precision assembly. Although NASA accepted this proposal, the methodology should have alerted NASA management to the fragility of the process, the possibility of gross error (that is, mistake in the process), and the need for continued care and consideration of independent tests.

The history of spherical aberration in the primary mirrors of Ritchey-Chretien telescopes was known to some of the optical scientists involved, but did not lead to specific recommendations early in the Project. Late in the Project an advisory group did call out the risk of gross error and suggested simple tests to check for such errors. This recommendation was not seriously considered, primarily due to total lack of concern that such a risk was reasonable, but also in view of cost and schedule problems.

Several methods of detecting the flaw were inherent in the testing, but Project management did not recognize the value of or need for independent tests. Project management was concerned about the performance specifications and directed a subcontract to Eastman Kodak Company for an alternate primary mirror. The Eastman Kodak mirror was fabricated and tested using quite different techniques. The mirror or the instrumentation could also have served as cross-checks for gross error. Such error checks were not made, again due to total lack of concern about the possibility of gross error. Project management failed to identify a significant risk and therefore failed to consider mitigating actions. A formal discipline such as fault-tree analysis might have assisted the manager in directing his attention to this risk.

[10-3] **B. MAINTAIN GOOD COMMUNICATION WITHIN THE PROJECT**

While proper delegation of responsibility and authority is important, this delegation must not restrict communication such that problems are not subject to review. In this case, the Optical Operations Division of P-E was allowed to operated in an artisan, closed-door mode. The impermeability of this Division seems astounding. The optical designers at P-E did not learn how their designs were being implemented; e.g., if the designer of the null correctors had been following their use, the data from the INC and the RNC likely would not have been discounted. The data indicating the flaw was of great concern to some members of the division. Testimony indicates that their concerns were addressed at the level of the head of metrology and the division manager, but were not satisfied by the decision to rely only on the RNC data and remained deeply concerned. Their concerns and the data which caused them did not seem to come to the attention of anyone external to the division. P-E management should have been sensitive and open to these concerns. The P-E Technical Advisory Group should have found out what was going on in the Division and insisted on reviewing in-process data. NASA Project management should have been aware that communications were failing with the Optical Operations Division.

Contributing to poor communications was an apparent philosophy at MSFC at the time to resolve issues at the lowest possible level and to consider problems that surfaced at reviews to be indications of bad management.

A culture must be developed in any project which encourages concerns to be expressed and which ensures that those concerns which deal with a potential risk to the mission cannot be disposed without appropriate review, a review which includes NASA project management.

C. UNDERSTAND ACCURACY OF CRITICAL MEASUREMENTS

The project manager must understand the accuracy of critical measurements. P-E concluded, based on design considerations, that the RNC was the only test device which could achieve the required precision. They stated that its performance could not be determined by optical test but would be determined by component and assembly measurements which could be made in situ. P-E engineers regarded the RNC as "certified" and the INC and RvNC as "uncertified." The terms were not defined, and "certification" was not documented. P-E discounted evidence of spherical aberration from INC and RNC measurements on the basis of "uncertified" status. In fact, the Board reviewed a recent as-built error analysis of both devices. The review showed the RNC to be [10-3] accurate to 0.02 wave rms and the INC to 0.14 wave rms. This indicates that the INC is a factor of three more accurate than the error observed in the INC/RNC interferograms. While in-process data were not subject to external review, which is another lesson, the methodology of test instrument use was reviewed by P-E and NASA management. This review could and should have questioned the judgment not to use the INC or the RNC as independent checks of the *accuracy* of the RvNC even though the *precision* was not to specification. Project management must understand critical tests and measurement.

In addition, the project management must seriously consider the classification of test equipment that directly impacts the flight hardware. The RNC was classified as standard test equipment, which means that the RNC was not subject to the rigorous documentation and review requirements demanded of items classified as flight hardware equipment. Under the contract, there were no Government regulations requiring that records for the RNC be maintained. Considering the importance placed on the RNC in the test program, management should have upgraded the level of classification of this equipment.

Key decisions, test results, and changes in plans and procedures must be adequately documented. In preparing such documentation, individuals are forced to review and explain inconsistencies in the test data. This also provides a communication link to those individuals who are responsible for overseeing the project.

D. ENSURE CLEAR ASSIGNMENT OF RESPONSIBILITY

Project managers must ensure clear assignment of responsibility to QA and Engineering. NASA QA personnel were not optical system experts. The Project relied upon P-E Engineering to establish test and fabrication procedures, and P-E or NASA QA generally verified that Engineering approved and certified accomplishment of procedures. However, at times, NASA management seemed to rely on QA to verify the adequacy of procedures and the fact that they were satisfactorily accomplished. This lack of clarity apparently led to incomplete documentation and may have contributed to faulty procedures. The project manager must know what QA can and cannot do, and when it is necessary to rely on engineering for verifying its own procedures, management should be alert to the need for independent checks.

Quality assurance, to be truly effective, must have an independent reporting path to top management.

[10-4] **E. REMEMBER THE MISSION DURING CRISIS**

There will be a period of crisis in cost or schedule during most challenging projects. The project manager must be especially careful during such periods that the project does not become distracted and fail to give proper consideration to prudent action. At one point in the fabrication cycle of the primary mirror, an urgent recommendation for independent tests to check for gross error entered the system, but was apparently not acted upon. Again, at the completion of mirror polishing, the final review of data for a final report was abandoned and the team reassigned as a cost-cutting measure.

F. MAINTAIN RIGOROUS DOCUMENTATION

The project manager should ensure that documentation covering design, development, fabrication, and testing is rigorously prepared, indexed, and maintained. Because quality, at a minimum, consists in meeting requirements, it is not possible to determine whether the necessary quality is being achieved if the requirements are not set forth in sufficient detail and maintained in retrievable archival form. Adequate documentation also helps maintain a disciplined approach to fabrication and testing processes, especially with so complicated a project as the HST.

Document IV-20

Document title: *Report of the Advisory Committee on the Future of the U.S. Space Program*, (Washington, DC: U.S. Government Printing Office, December 1990), pp. 47-48.

On July 25, 1990, the White House announced the creation of a blue-ribbon panel to make a comprehensive assessment of the status of the U.S. civilian space program. This announcement was the result of increasing dissatisfaction on the part of the National Space Council with both NASA's response to President Bush's 1989 call for what came to be known as the "Space Exploration Initiative" and NASA's technical and mangerial performance as evidenced by the grounding of the space shuttle in June 1990 because of problems in its fuel lines and the discovery that the Hubble Space Telescope had been launched with an improperly shaped primary mirror. The original intent was to have the panel report only to the vice president in his role as the chairman of the National Space Council, but NASA Administrator Richard Truly successfully argued that it should also report to him. The panel was chaired by Martin Marietta Corporation Chief Executive Officer Norman R. Augustine, and it was composed of a cross-section of individuals knowledgeable about all aspects of U.S. space efforts. The panel held a series of hearings and conducted fact-finding visits around the country between September and November 1990. It issued its report on December 17, 1990. Published here are the principal recommendations of the commission.

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[47] **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 (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 + 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 mission 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 [48] 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....

- That the current headquarters structure be revamped, disestablishing the positions of certain existing Associate Administrators...

- 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 principle 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) 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 on 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.