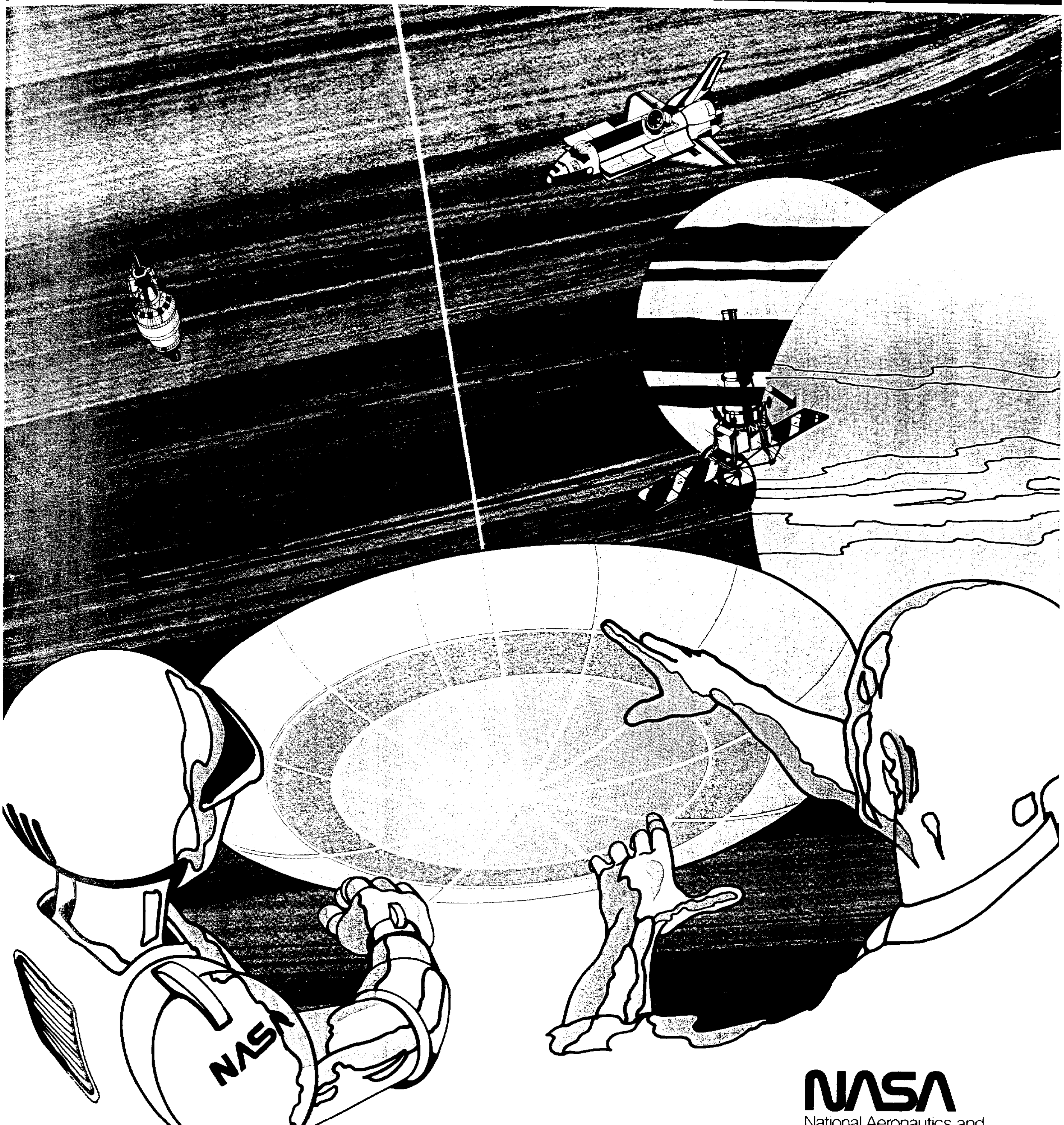
ANNUAL REPORT

Aerospace Safety Advisory Panel

MARCH 1991



NASA
National Aeronautics and
Space Administration

NASA

Aerospace Safety Advisory Panel

Annual Report

March 1991

Aerospace Safety Advisory Panel
Code Q-1
NASA Headquarters
Washington, DC 20546

Tel: (202) 453-8971

NASA

National Aeronautics and
Space Administration

Washington, D.C.
20546

March 1991

Reply to Attn of: Q-1

Honorable Richard H. Truly
Administrator
NASA Headquarters
Washington, D.C. 20546

Dear Admiral Truly:

The Aerospace Safety Advisory Panel (ASAP) is pleased to submit its Annual Report covering the period from February 1990 through January 1991. As in the past, this report provides you with the findings and recommendations of the Panel and supporting material. We request that you respond only to the findings and recommendations that can be found in Section II of the report.

The ASAP would like to commend NASA for its strict adherence to the principle of *Safety First, Schedule Second* during a year marked by numerous problems and trials. Although planned activities had to be postponed or canceled, much was learned from the process of solving the problems that arose. This will make the entire NASA organization stronger and better able to cope with future contingencies. The Panel encourages NASA to continue to approach its problems in this same prudent manner.

The enclosed report highlights the principal areas for which we have comments. Many of these are continuations of concerns, suggestions, and observations made in previous ASAP reports. Several of our long-term concerns, including the need for a crew rescue capability on Space Station, were also echoed independently by the Augustine Committee.

The Panel also applauds NASA for its outstanding aeronautical research. Programs such as the X-29 high angle of attack tests at Dryden, the Langley investigations of wind shear, heavy rain and lightning strikes, and the Ames work on crew coordination and rest cycles have made significant contributions to aviation safety. Their continuation and expansion are certainly in the best interests of the entire aviation community.

The Panel continues to enjoy an excellent working relationship with the people of NASA and its contractors. We are grateful for the assistance we have received over the past year and look forward to continuing our work in 1991. We solicit your guidance and suggestions on areas for us to explore that will be of maximum benefit to the safety of NASA's operations.

Very truly yours,

Norman R. Parmet

Norman R. Parmet
Chairman, Aerospace
Safety Advisory Panel

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FOREWORD

The past year at NASA has been characterized both by noteworthy successes and highly publicized problems. For example, despite the flaw in the Hubble Space Telescope major mirror, this instrument has already made a number of significant achievements. The Space Shuttle Program, after a hiatus waiting for resolution of hydrogen leaks, successfully launched STS-38 and STS-35 missions within a 2-week period. The Galileo spacecraft, on its way to Jupiter, took unprecedented photographs of the earth and moon. The results of research and technology advancements achieved with new and futuristic aircraft exemplified by the X-29 high-angle of attack flight test program are also noteworthy.

The Panel developed 34 findings and recommendations. Highlights of the findings are:

Orbiter Structural Upgrades: Wing and fuselage upgrades have been scheduled for OV-102 during its July to December 1991 maintenance period. Similar plans are being developed for OV-103 and OV-104. These should be priority items.

Orbiter Extended Mission Time: There are uncertainties associated with the ability of crew members to perform Orbiter landings after prolonged exposure to zero-G. A redundant autoland capability or other reliable backup should be included to cover possible diminishment of crew capacity.

Orbiter Computers: With Orbiter life extending well into the 21st century, it will be necessary to upgrade its computer systems several times. This requires immediate planning for implementation.

The Space Shuttle Main Engine Alternate Turbopump Development Program: This program is to provide sturdier high-pressure turbopumps and needs close attention to ensure its planned component testing is not truncated to meet engine-level testing milestones.

Solid Rocket Booster Aft Skirt: The planned use of the existing Solid Rocket Booster aft skirt for the new Advanced Solid Rocket Booster should be reexamined to ensure that an inherent Factor of Safety of 1.4 is obtained.

Solid Rocket Motor Test Stand: The plan to move the unique T-97 Dynamic Test Stand from its current location in Utah to the Stennis Space Center for the testing of the Advanced Solid Rocket Motor will leave the current Redesigned Solid Rocket Motor program without a dynamic test facility to support operations into the late 1990s.

Assured Shuttle Availability Program: The majority of safety and reliability enhancements that the Panel previously had suggested for inclusion in this Program are in progress at this time. Current information indicates that under this same program title, NASA also is undertaking a program of Space Shuttle modifications with a primary objective of life extension and elimination of obsolescence. These objectives are both worthy of pursuit, but should not be included under the same program title.

Orbiter Logistics: The current logistics and support systems are continuing to evolve satisfactorily, and the expansion of component overhaul and repair facilities at the Kennedy Space Center is most impressive. However, the total time for repair and turnaround of components and Line Replaceable Units remains, in general, too long.

Space Station Freedom Program: A principal area of concern is the lack of a sound systems engineering and systems integration effort associated with a lack of functional requirements definition.

Aircraft Operations: Past ASAP reports have cited concerns over the extent of NASA Headquarters' involvement in the safety of the operation of NASA's aircraft. Within the past few months, new and commendable activities have appeared that are providing more and better teamwork between all concerned.

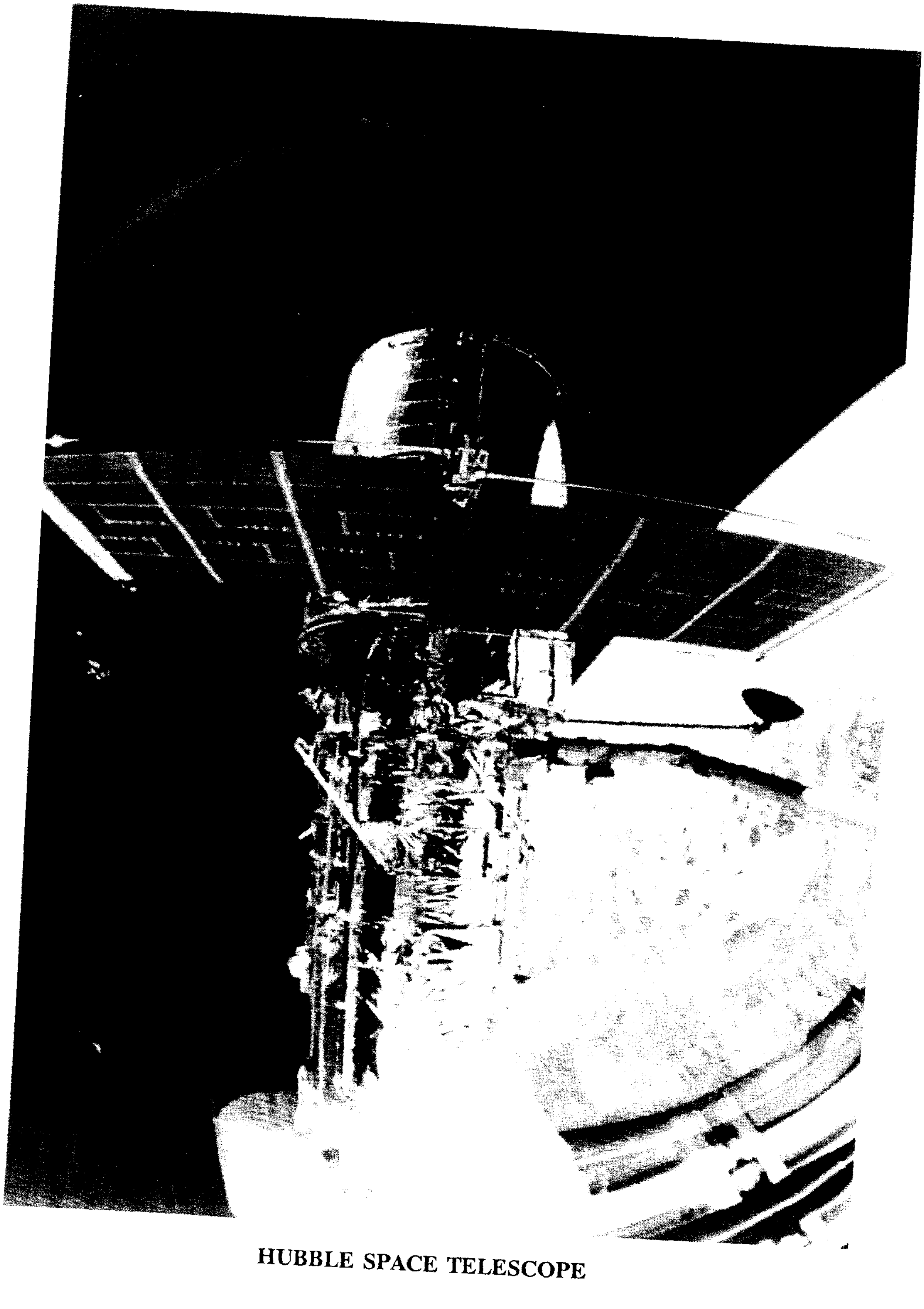
Mishap Reporting: The implementation of NASA Management Instruction 8621.1E "Mishap Reporting and Investigation" presents a comprehensive implementation approach to reporting and investigation procedures. However, the more extensive use of human factors expertise and the formal investigation of "close calls" should be included.

NASA Facilities: NASA has undertaken an organized 5-year program to renovate, rehabilitate, and enhance significant ground facilities that are, in fact, true national assets for aerospace research, development, and operations. This effort should be continuous.

As this report was being written, the report of "Advisory Committee on the Future of the U.S. Space Program" (the Augustine Committee) was published. Many of the Augustine Committee's recommendations reflect views the Panel has voiced for years.

The Panel and the Augustine Committee have reflected a common concern over NASA's willingness to undertake more than realistically could be supported within the allocated resources. By overreaching, NASA has stretched its scientific, engineering, and administrative capabilities excessively, thereby creating an environment where safety concerns compete with operational commitments, such as schedules.

Finally, it should be noted that as of this writing, the Space Shuttle has achieved 13 successful launches since the Challenger accident. This can be attributed in large part to the incorporation of extensive safety and reliability enhancements, many of which were recommended in the past by the Panel.



HUBBLE SPACE TELESCOPE

I. INTRODUCTION

I

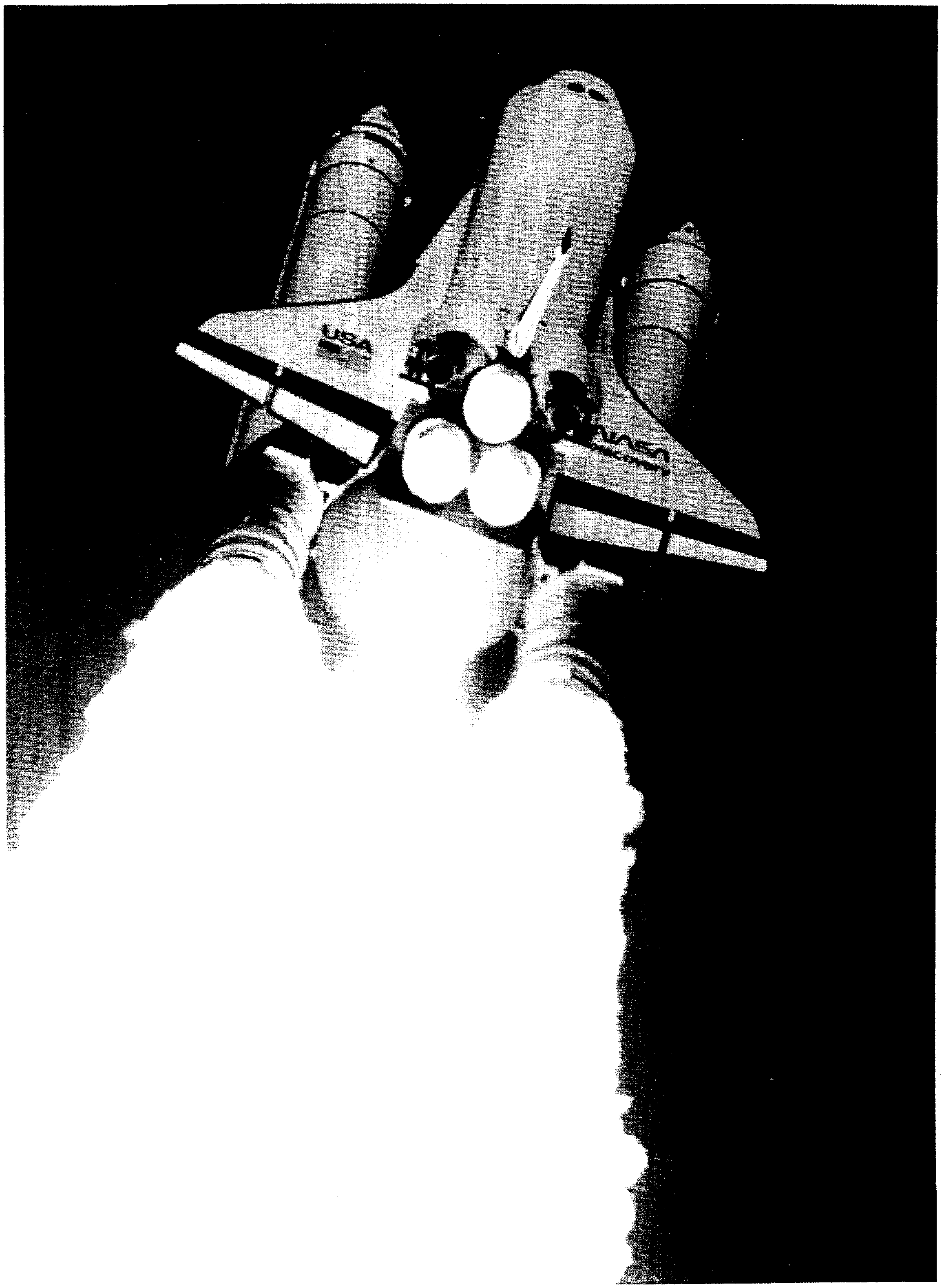
INTRODUCTION

For NASA, the year 1990 was highlighted by six Space Shuttle flights, the first landing at the Kennedy Space Center (KSC) in 5 years, three spectacular planetary encounters, many successful aeronautic research and technology programs, and a flood of criticism over the flawed Hubble Space Telescope and the Space Shuttle hydrogen leak problems.

NASA's approach to the resolution of the Shuttle hydrogen leak problems was a commendable example of the principle of "safety first, schedule second." NASA took these steps essential to ensure safety of flight by finding the source of the leaks, understanding the reasons for them, and fixing the hardware.

Section II, "Findings and Recommendations," result from the many visits made by Panel members to NASA and contractor installations. Section III, "Information in Support of Findings and Recommendations," provides information in support of these findings and recommendations. Section IV, "Appendices," contains factual data about the Panel as well as the NASA response to the ASAP Annual Report of March 1990 and a chronology of Panel activities.

There have been a number of membership changes to the Panel during the past year. Joseph F. Sutter was replaced by Norman R. Parmet as Chairman of the Panel. Mr. Sutter continues to work with the Panel as a consultant. Vice Admiral Robert F. Dunn (USN Ret.) has been appointed as the newest member of the Panel. Gerard W. Elverum, Jr., retired from the Panel after serving 7 years as both a member and a consultant. Richard D. Blomberg has moved from his position as a consultant to the Panel to a member. This maintains a cadre of experienced personnel while bringing on board "new blood" to maintain a fresh outlook.



SPACE SHUTTLE DISCOVERY LIFT-OFF

II. FINDINGS AND RECOMMENDATIONS

II

FINDINGS AND RECOMMENDATIONS

A. SPACE SHUTTLE PROGRAM

SPACE SHUTTLE ELEMENTS

Orbiter

Finding #1: NASA has planned to implement the wing/fuselage modifications indicated by the results of the 6.0 load analysis. Modification work has been scheduled for OV-102, and plans are being developed for the remainder of the fleet.

Recommendation #1: The implementation of these modifications should be accomplished as soon as possible so that the restricted flight envelope (green squatcheloid) parameters can be safely upgraded.

Finding #2: The uncertainties surrounding crew performance after extended stays in space suggest a need for an alternative to manual landings.

Recommendation #2: The Space Shuttle Program should complete the development of a reliable autoland system for the Orbiter as a backup.

Finding #3: With plans to extend Orbiter use well into the next century, it will be necessary to upgrade the Orbiter computer systems several times. The present, rather ad hoc, approach of treating each upgrade as an independent action will be unsatisfactory for the long term.

Recommendation #3: NASA should accept the need for an upgrade involving a complete software reverification approximately every 10 years. A study should be undertaken to plan a path of evolution for all future changes in avionics computer hardware and software for the life of the Space Shuttle Program. The study should involve independent assessment to ensure the broadest possible perspective.

Finding #4: The Space Shuttle flight software generation process is very complex. It includes numerous carefully designed safeguards intended to ensure that no faulty software is ever loaded. When errors have occurred, or when concerns have been raised about steps in the procedure, new safeguards have been added. The whole process is long, complicated, and involves a plethora of organizations and computers.

Recommendation #4: NASA should conduct an independent review of its entire software generation, verification, validation, object build, and machine loading process for the Space Shuttle. The goals should be to ascertain whether the process can be made less complex and more efficient.

Space Shuttle Main Engine (SSME)

Finding #5: The SSME is now available in sufficient numbers to support all the Orbiters. A suitable number of spare engines are available at the launch site.

Recommendation #5: Keep up the good work while recognizing any demands imposed by changes in planned launch rates.

Finding #6: The program to develop safety and reliability improvements to the current SSME is meeting with a large degree of success. However, some components, like the pump end of the High-Pressure Oxidizer Turbopump (HPOTP) and the two-duct power head have not been successful. The bearing housing at the pump end of the HPOTP has not met its objectives, and an operational solution has been devised to accommodate the resulting small number of allowable reuses between overhauls. Premature combustion chamber cracking and injector erosion were experienced with the two-duct powerhead.

Recommendation #6: Continue the development and certification of the safety improvements so that they may be incorporated at the earliest possible time.

Finding #7: The Alternate Turbopump Program has encountered a number of design problems during testing. Fixes are being incorporated and fed into development testing. Planning for completion of component-level testing and entering the engine-level test phase is very optimistic, especially in view of the difficulties experienced in completing test runs on the component test stand.

Recommendation #7: Schedule pressures can engender the temptation to truncate the component test plans and objectives. Do not compromise the objectives and thoroughness of the planned component test program to start engine-level testing at the time currently scheduled.

Redesigned Solid Rocket Motor (RSRM) and Advanced Solid Rocket Booster (ASRB)

Finding #8: NASA is planning to use the existing Solid Rocket Booster aft skirt on the Advanced Solid Rocket Booster. The requisite Factor of Safety is to be achieved by biasing the spherical bearings at the hold-down posts.

Recommendation #8: The aft skirt design for the Advanced Solid Rocket Booster should be inherently strong enough to achieve a Factor of Safety of 1.4.

Finding #9: The Redesigned Solid Rocket Motor manufacturer has made impressive strides in the quality of industrial operations. Incorporation of existing state-of-the-art automation for manufacturing and assembly processes is continuing.

Recommendation #9: Continue the industrial enhancements to achieve further reduction of requirements for hands-on labor and increased product quality.

Finding #10: The use of the Advanced Solid Rocket Motor and Redesigned Solid Rocket Motor during the same time frame will pose procedural and test challenges because of their different configurations and performance characteristics.

Recommendation #10: NASA and its contractors should develop a well integrated plan for such concurrent operations.

Finding #11: The test program for the Advanced Solid Rocket Motor/Advanced Solid Rocket Booster has been well planned and uses the many lessons learned from the ongoing Redesigned Solid Rocket Motor project. There are, however, a number of uncertainties including characterizing the physical and manufacturing properties of the case material.

Recommendation #11: The project should provide an allowance for contingencies beyond those indicated in the current schedules and budgets to account for proper closure/resolution of expected test results.

Finding #12: NASA has embarked upon an ambitious program of automation for manufacturing the Advanced Solid Rocket Motor. The new automation will be a significant step forward and an impressive accomplishment. However, there are concerns about the feasibility of completing automation of this scale in the time frame indicated. Therefore, there may be significant delays in the availability of the Advanced Solid Rocket Motor.

Recommendation #12: NASA should be prepared to extend use of the Redesigned Solid Rocket Motor beyond current plans.

Finding #13: It is planned to move the highly instrumented T-97 Solid Rocket Motor Dynamics Test Stand from Utah to the Stennis Space Center in Mississippi for use during the Advanced Solid Rocket Motor Program rather than constructing an equivalent new test stand. This will leave the current Redesigned Solid Rocket Motor Program without a dynamic test facility support.

Recommendation #13: Retain the current T-97 dynamic test stand at the Utah site to support the Redesigned Solid Rocket Motor Program. A new dynamic test stand should be constructed for the Advanced Solid Rocket Motor at Stennis Space Center.

External Tank (ET)

Finding #14: The external tank project is moving along very well.

Recommendation #14: Keep up the good work.

Finding #15: This past year, NASA management has postponed Space Shuttle launches when technical uncertainties existed, declared a hiatus during the Christmas season and interrupted launch operations until the cause of hydrogen leaks could be determined and resolved. This is clear evidence of NASA management's commitment to the principle of "safety first, schedule second."

Recommendation #15: NASA management should maintain this policy even as Shuttle launches become more frequent.

Launch And Landing Operations

Finding #16: Reports indicate that launch processing operations at the Kennedy Space Center (KSC) are being carried out with a declining rate of incidents. This is a trend in the right direction since the extreme sensitivity of Shuttle launch processing requires reducing errors to the lowest possible levels.

Recommendation #16: KSC, the Shuttle Processing Contractor, and associate contractors should continue to make all possible efforts to reduce incidents. However, care must be exercised to ensure that any observed decrease in incident reports is not merely an artifact of the reporting system. In particular, if management's response to incident reporting is perceived as punitive in nature, the net result may be a suppression of reporting with a resultant reduction in the information available to management on which to identify problems and design remedial actions. Total Quality Management (TQM) techniques can be of great assistance. Likewise, the inclusion of human factors professionals on incident investigation teams can be very beneficial. Therefore, KSC should consider both an enhanced TQM program and a broader use of human factors.

Finding #17: There is a perception among some workers at KSC that disciplinary actions for errors are overly severe.

Recommendation #17: NASA and its contractors should make every effort to communicate the facts and rationale for disciplinary actions to the work force and involve workers in incident reviews. TQM techniques can be of great assistance. There is simply no substitute for sincere communication between management and labor in dispelling negative perceptions.

Finding #18: There are cases in which recurring waivers are sought and issued for the same subsystem or component on successive Space Shuttle flights. For example, waivers have had to be issued to fly with the tumble valve disabled on the external tank.

Recommendation #18: Continuing waivers for the same condition should not be permitted. If it is deemed acceptable to fly repeatedly with a configuration that varies from specifications, the specifications should be altered rather than risk diluting the significance of waivers by making them routine. For example, the underlying specification for the tumble valve could be changed to require its inclusion only on high inclination launches.

Mission Operations

Finding #19: The Mission Control computer support system is quite old, relatively slow, and has monochrome displays primarily of tabular data. The advantages of applying current technology to Mission Control are being explored with the Real-Time Data System at the Johnson Space Center (JSC).

Recommendation #19: NASA should embark upon a systematic process to replace the old Mission Control system with one based upon up-to-date computer and human interface system technology.

ASSURED SHUTTLE AVAILABILITY PROGRAM

Finding #20: The majority of the safety and reliability enhancements that the Panel suggested be included in the Assured Shuttle Availability Program have been undertaken by NASA. It now appears that under this same label, NASA is undertaking a program of Space Shuttle modifications whose primary objectives are life extension and the elimination of obsolescence. This could lead to confusion.

Recommendation #20: The Panel urges that the two sets of objectives be pursued through independent, separately titled, but coordinated programs.

LOGISTICS AND SUPPORT PROGRAM

Finding #21: The Orbiter logistics and support systems are continuing to evolve satisfactorily. The expansion of component overhaul and repair facilities at the launch site and in the nearby areas is most impressive. Liaison between all

NASA Centers and contractors appears to be excellent, and the control and communications networks are being further improved.

Recommendation #21: Continue with the philosophy of centralizing Orbiter spares support and overhaul/repair activity in the KSC area. Good work!

Finding #22: The total elapsed time for repair and turnaround of many repairable components is still too high. Delays in accomplishing failure analysis appears to be a major part of the problem.

Recommendation #22: Continue to take all steps necessary to reduce turnaround time.

Finding #23: While the overall cannibalization problem appears to be under good control, there are still a few shortages of high-value items such as Auxiliary Power Units (APUs).

Recommendation #23: Review, once again, the critical supply issues in long-lead and high-value items to ensure an adequate spares level to avoid the safety problems associated with cannibalization.

Finding #24: Out-of-production, aging, and obsolescent parts are a growing problem.

Recommendation #24: Increased emphasis should be given to ensuring the availability of sufficient quantity of up-to-date hardware.

Finding #25: There does not appear to be a comprehensive and realistic plan for scheduling and accomplishing major overhaul of the Orbiter fleet.

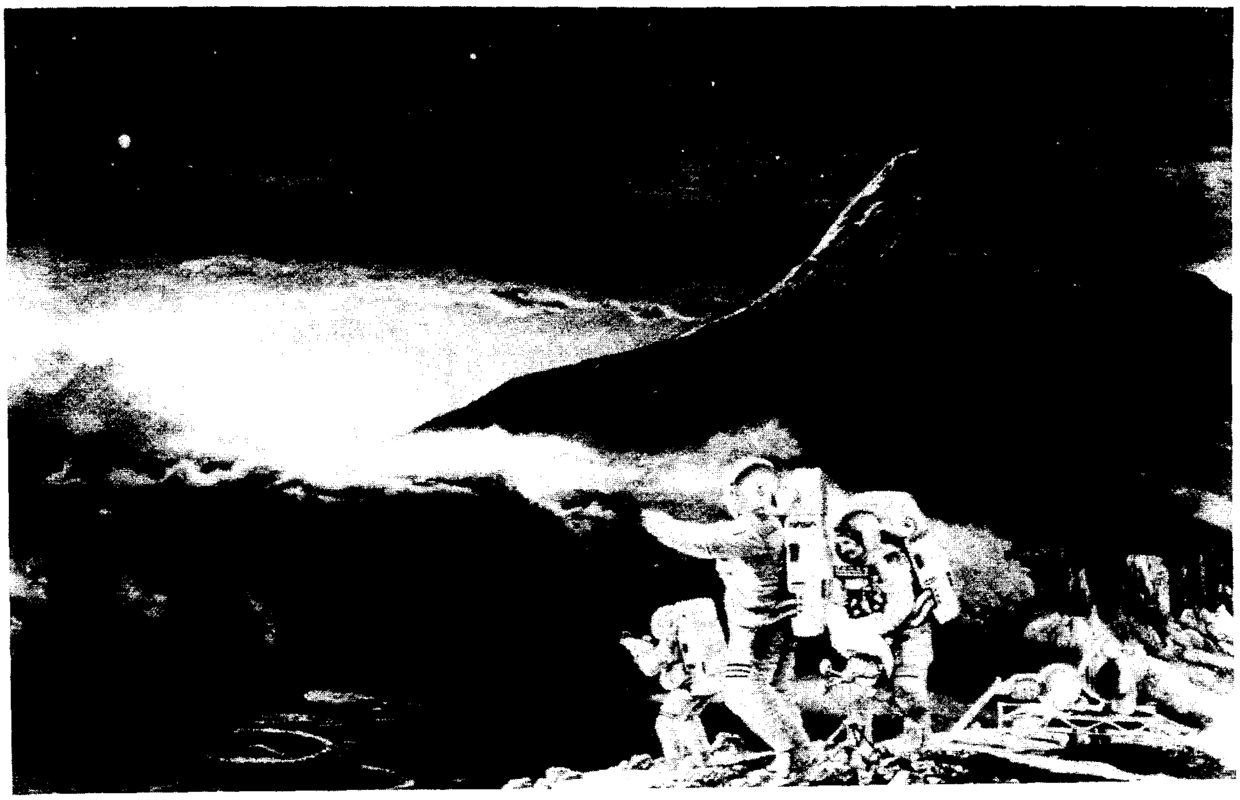
Recommendation #25: To help ensure structural integrity of each vehicle, much greater effort must be devoted to these tasks. A comprehensive program should be developed for the orderly overhaul of Orbiters that are expected to operate into the 21st century.

B. SPACE STATION FREEDOM PROGRAM

Finding #26: The Space Station Freedom Program has been plagued by technical, managerial, and budgetary difficulties since its inception. The instability of this program coupled with extensive externally stipulated design constraints has made it extremely difficult to conduct this program in a sound and orderly manner. The program has suffered from the absence of a clearly defined primary purpose that has resulted in an incomplete specification.

Also, there has been a lack of effective systems engineering and systems integration activity.

Recommendation #26: The purpose and funding of the redefined Space Station Freedom Program must be firmly agreed upon by the Congress and NASA. Then, NASA should be permitted to organize and manage the program. Systems engineering, system integration, and risk management must be integral and vital parts of the revised program.



C. AERONAUTICS

AIRCRAFT OPERATIONS

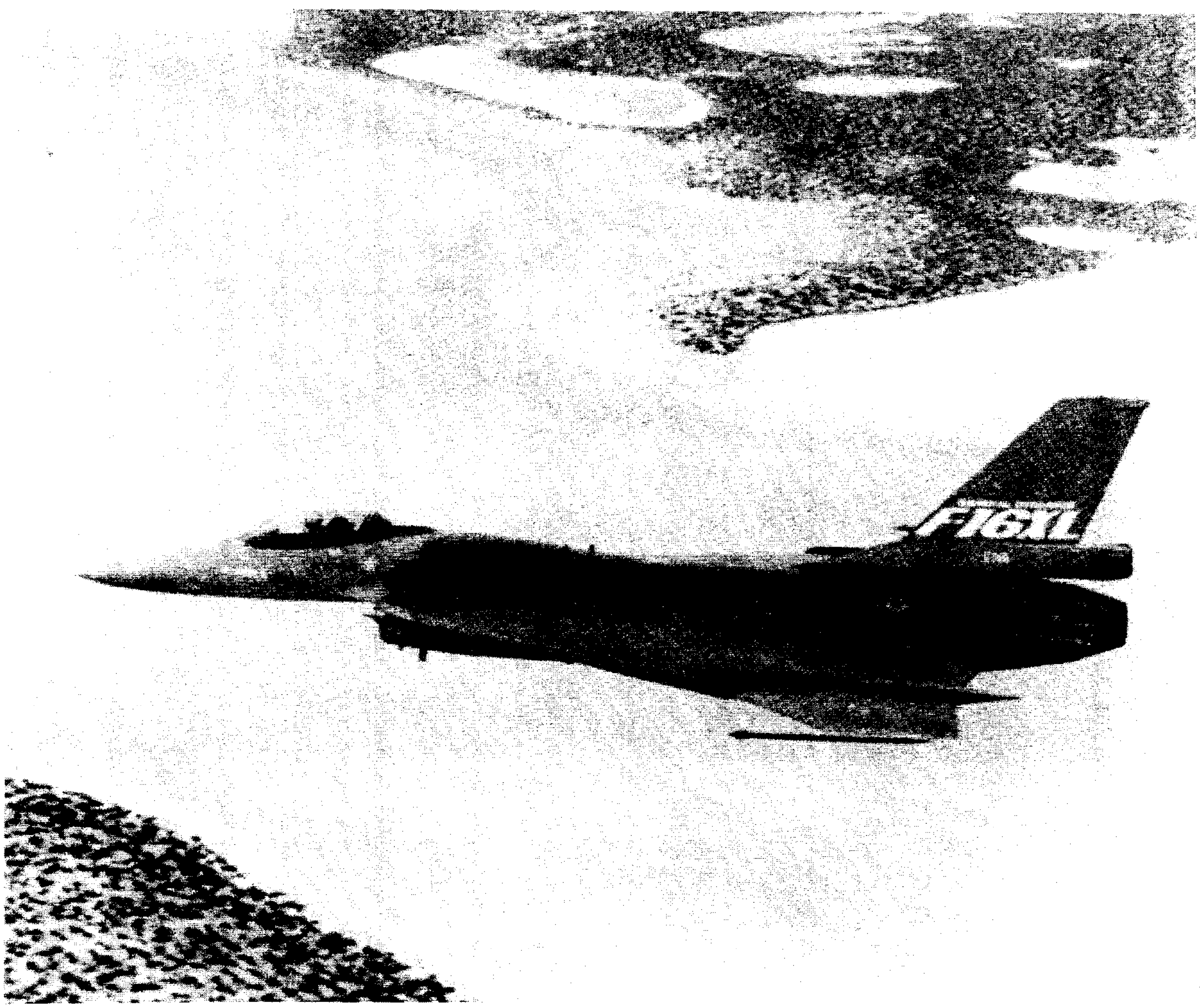
Finding #27: Past ASAP reports have cited concerns over the extent of Headquarters involvement in aircraft operations safety. During the past year, a reorganization and redelineation of Headquarters safety responsibilities has gotten underway.

Recommendation #27: NASA should follow through with the implementation of Headquarters policies regarding the safety of the operation of NASA's aircraft.

RESEARCH AND TECHNOLOGY

Finding #28: The joint Air Force/ NASA high angle of attack program conducted at the Dryden Flight Research Facility has been a model of safe and efficient experimental flight testing.

Recommendation #28: NASA should document the experience of this flight test program in the tradition of the NASA/NACA flight test reporting.



D. SAFETY AND RISK MANAGEMENT

MISSION SUPPORT

Finding #29: The use of Fault Tree Analysis and Failure Modes and Effects Analysis techniques proved to be valuable in solving the hydrogen leak problems on STS-35 and STS-38. Their use led to the identification of probable sources of the hydrogen leaks, the probable causes of these leaks, and the nature of the corrective actions needed.

Recommendation #29: Use of these techniques for problem resolution should be encouraged throughout NASA. Suitable training programs should be established to ensure proper implementation.

TOTAL QUALITY MANAGEMENT (TQM)

Finding #30: NASA has a TQM program intended to improve quality and productivity within NASA and its contractors. The implementation of the TQM (or its equivalent) concept, however, has been quite variable across the NASA Centers and contractors.

Recommendation #30: The principles of TQM have merit when implemented by a dedicated and concerned management. NASA should implement a consistent TQM methodology that ensures adherence to those principles and participation of all levels of the work force.

SAFETY REPORTING SYSTEMS

Finding #31: NASA has a management instruction (NMI 8621.1E) that addresses "Mishap Reporting and Investigation." This NMI includes a specification of board composition. It does not, however, realistically address the need for human factors input in such investigations. It notes that if human factors are thought to be substantially involved, then human factor input is to be sought from a "NASA or resident NASA contractor physician" rather than a trained human factors expert. Also, this NMI does not require investigation of "close calls."

Recommendation #31: Inclusion of a member on the incident/accident investigation board with specific human factors expertise should be given much greater consideration. "Close-call" investigations should be more formalized.

E. OTHER

NASA FACILITIES

Finding #32: NASA has undertaken a well organized, 5-year program for safety and operational renovation/revitalization of some of its major experimental research facilities.

Recommendation #32: NASA and the Congress should continue to keep in focus the importance of preserving and periodically updating the physical plants and research facilities at NASA Centers. The current program should be continued and extended to cover the facilities that were not included because of funding limitations.

EXTRAVEHICULAR MOBILITY UNITS/ SPACE SUITS

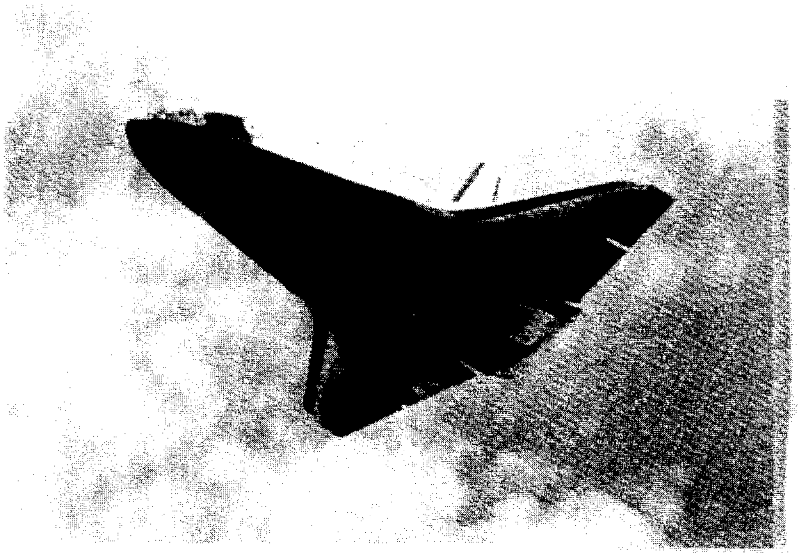
Finding #33: NASA's current plans for Space Station and the Space Exploration Initiative will inevitably involve the need for both planned and contingency extravehicular activities (EVA).

Recommendation #33: The planning and design for Space Station and other manned space exploration programs should make every attempt to minimize dependence on EVA. In addition, NASA should undertake the development of an improved Extravehicular Mobility Unit that eliminates or reduces the maintenance and operational problems inherent in the current suit designs.

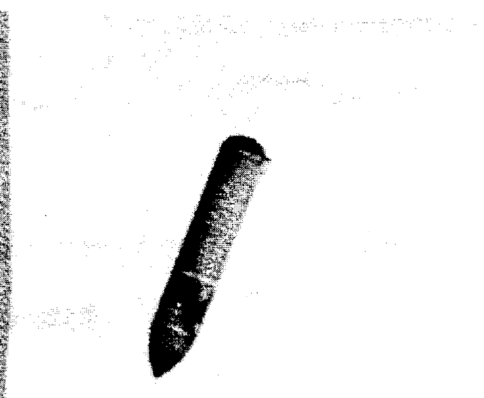
TETHERED SATELLITE SYSTEM (TSS)

Finding #34: The tethered satellite concept involves potentially operational activities that have never been attempted and that cannot be simulated on the ground before flight. Hazard studies and analyses have revealed the possibility of the Orbiter becoming adversely affected by the tether in the event of a malfunction during extension, while deployed, during retraction, or during stowage.

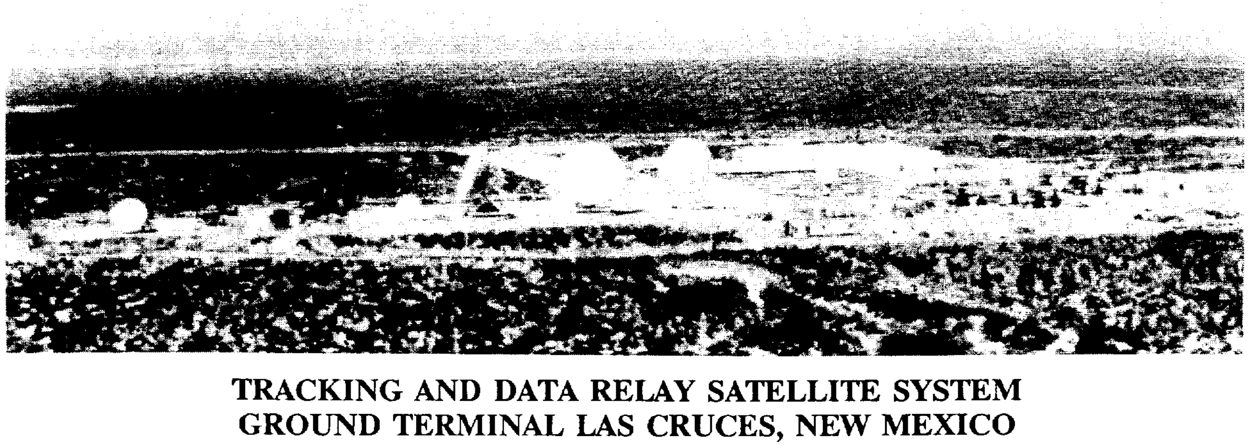
Recommendation #34: Program risk management should continue to focus on the results of the principal hazard analyses and their implication for Space Shuttle and satellite control.



SPACE SHUTTLE ATLANTIS
LANDING



EXTERNAL TANK AFTER RELEASE
FROM SPACE SHUTTLE



TRACKING AND DATA RELAY SATELLITE SYSTEM
GROUND TERMINAL LAS CRUCES, NEW MEXICO

III. INFORMATION IN SUPPORT OF FINDINGS AND RECOMMENDATIONS

III

INFORMATION IN SUPPORT OF FINDINGS AND RECOMMENDATIONS

A. SPACE SHUTTLE PROGRAM

SPACE SHUTTLE ELEMENTS

Orbiter

(Ref: Finding #1)

The Space Shuttle Program Office has decided to implement the necessary structural modifications to the Orbiter wings and certain fuselage areas to meet the loads that will be encountered in the desired flight envelope. When completed, the vehicle will meet its structural specifications. These modifications are planned to be accomplished during the major maintenance and inspection periods scheduled for all of the Orbiters starting with Orbiter OV-102 during the latter half of 1991. The other Orbiters will be modified in a similar manner at appropriate later dates. The modification will expand the allowable flight envelope thus, increasing launch probabilities.

In the Panel's March 1990 Annual Report, recommendation #9 stated:

> "As the large reduction of airloads on the vertical tail has been obtained by a revised analysis only, the reduction should be confirmed by an independent means such as in-flight strain gage measurements or an independent analysis."

In response, the Space Shuttle Program Director requested the Director for Structures for the Langley Research Center (LaRC) to perform an independent assessment of the Orbiter vertical tail loads. The results of that assessment were provided to the Panel. The technical conclusion of the LaRC team was as follows:

> "The briefing given to the LaRC team and the data reviewed was very convincing. In our opinion, the data bases (developed using a combination of analytical and test data and validated by a combination of ground and flight test measurements) are reasonable; the methods and models used to predict the vertical tail loads are appropriate; and the current vertical tail load predictions are conservative. Based on these conclusions, it is our opinion that an additional independent analysis is not required and in-flight measurements of vertical tail-loads, beyond what is already being accomplished, is not necessary."

The Panel will further clarify this information with the members of the LaRC team.

In-flight strain gage data are required to validate the 6.0 loads predictions. This requires strain gages that are properly installed and oriented and then verified under known loads. The Panel believes it is preferable to accomplish this verification prior to flight. The more than 250 strain gages on the wing are sufficient to permit the calculation of valid influence coefficients if the gages are properly oriented. The Panel's concern is that it may not be possible to calculate the required transfer functions if the load tests are conducted only after flight.

(Ref: Finding #2)

Potential human performance problems can arise from either extended normal operations that exceed the knowledge base for humans in space or from unexpected (i.e., nonnominal) and even unforeseen (i.e., unexpected and not part of the training syllabus) events, which will certainly occur during long-duration missions. This raises the following questions:

- What is the impact of the planned work timelines, extended periods of zero-G, and long EVA work efforts on the ability of the crew to recognize, evaluate, and cope correctly and in a timely manner with unforeseen events?

- Are there predictors of performance and capacity decrements that can be used to avoid negative impacts on operations or safety?

- Are human performance-based criteria being considered as part of the assessment of various extended duration missions?

The unknown human limits, performance, and capacity are a potential problem to future long-duration missions because there are no available measures to indicate when spare capacity has been exhausted. The potential problem may also actually be exacerbated by the extensive training crews receive. This repetitive training including part-task simulation makes it possible for crews to perform planned tasks even when they are at the limit of their capacity. Unless the crew starts making errors on planned tasks or there are biomedical indications of difficulty, there is no way to estimate if contingencies can be handled.

Specific attention should be given to the ability of the crew to land an Orbiter safely after Extended Duration Orbiter missions. Part of this effort should be the qualification of the Space Shuttle's automatic landing capability so that it will be available if there is a problem with manual landings after extended stays in orbit.

(Ref: Finding #3)

The Space Shuttle computer system faces a continuing evolution in flight requirements and increased equipment obsolescence accompanied by greater and more expensive maintenance problems. There is a large list of waiting software change requirements covering such things as the Extended Duration Orbiter missions, crew requested changes, mission-specific changes, and general improvements. Due to the rapid evolution of computer technology, it is difficult to keep any given generation of computer equipment in use for more than a few years. After that, it becomes increasingly difficult to obtain replacement parts. There is also the opportunity to incorporate new capabilities. In the projected 30-year horizon for the Space Shuttle, it will be necessary to upgrade the system several times.

Until now, the program has focused on how to solve specific individual problems, e.g., how to get more memory or more speed out of the existing Space Shuttle computer system, and do it with minimal reverification effort. This approach has not been cost effective.

There now are a number of arguments that favor starting a study for long-term Space Shuttle avionics computer evolution. They are based on events that can be expected in 8 to 10 years. The hardware in the "new" general purpose computer will become obsolete and require replacement in about that time period. Also within that time period, the limit on available memory in the Space Shuttle computers will have been reached. Expansion with the "new" general purpose computer will not be possible without major software changes that would require massive reverification.

One might try to resolve this by freezing allowed changes to avoid requiring more memory (or require a balance between additions and deletions). Such freezing of allowed changes, however, is illusory. Changes in requirements or hardware are inevitable and will engender the need for software modifications. Major software companies have analyzed the problem, recognized the problems caused by requirement changes, sworn they will not allow any, and failed, ultimately recognizing that they had to allow changes in requirements.

The only two suggestions to solve Space Shuttle computer problems that the Panel has heard are: (1) to off-load some of the functions onto other computers, and (2) to redesign the entire computer system. The first is attractive because it has the potential for gradually expanding into the use of newer technologies while retaining the basic existing architecture for flight critical functions. This would significantly limit the amount of redesign necessary to evolve the computer system to use newer technology in comparison to a complete redesign of the system. However, this approach has not been studied beyond the concept phase. The feasibility of limiting the reverification required, however, is related to the coupling of the functions off-loaded to the global memory. The Panel suspects that some significant level of reverification will be necessary. The second alternative has not been explored.

The consequence of these arguments is that NASA will have to face very significant cost, time, and risk issues regarding the Space Shuttle computer system in 8 to 10 years regardless of the approach taken. Given a much more modest change, the "new" general purpose computer will have taken 8 years to reach first flight, it is most important that a significant study of the alternatives be initiated as quickly as possible. Since it appears likely that significant reverification costs must be faced in any event, significant changes must be made in 8 to 10 years, and the Space Shuttle Program is expected to run for another 2 or 3 decades, a study effort is needed to posture the program for future generations of avionics hardware and software, looking forward to at least 3 decades, not just to the next modification to be made.

Among the specific things that should be investigated are:

- Estimated code change request rates in each of the major categories — ascent, on-orbit, and descent — and their impact on key resources such as memory capacity, Central Processing Unit capability, and test facilities.

- An analysis of factors leading to subsequent future upgrades and an evolutionary plan that extends throughout the lifetime of the Space Shuttle Program. Such factors should include general purpose computer lifetime expectancies, spare parts availability, and expected future demands upon the system.

- At least two approaches to the problem: (1) a complete revision in the Space Shuttle computer system such as to make its components compatible with those of other long-term space programs, and (2) the off-loading of many functions to new computers, keeping the critical flight software in the general purpose computers or some new generation thereof.

- A technical plan for each alternative extending to subsequent future upgrades.

- The long-term cost trade-offs between the possibilities, including continuing verification costs.

It is particularly important that the study be performed from the perspective of evolution of the computer system over a 30-year period of time. To assist in conducting a thorough and broad study of possible approaches, it is also important that there be a degree of independence to the study team. That is, the study team should include people from outside the Space Shuttle Program office who have investigated similar problem within NASA, e.g., Ames Research Center or Jet Propulsion Laboratory personnel.

(Ref: Finding #4)

During the past year, concern was raised about the adequacy of the procedures used for preparing I-Loads, particularly the manual steps proposed for use on the day of launch and their propensity for human error. The JSC Safety and Mission Quality organization conducted a very thorough review of the entire process to determine the adequacy of the safeguards contained therein. A report on the activity is contained in "The I-Load Process Analysis" JSC document #24364 released in October 1990. They found that the safeguards in the system were adequate. They are to be commended for an excellent job.

Nevertheless, the Panel is left with a concern about the overall process for the generation and installation of the flight software. Despite the built-in safeguards, errors have occurred. The process is quite complex. Not only are there a great many organizations involved, they employ a variety of computer types and computer languages. Each organization provides a part of the total I-Load for a flight. Moreover, there are a large number of Control Boards to oversee and control the many steps. This complexity arose, apparently, during the development of the process as new requirements were addressed. It would appear that little attention was given to the effective integration of the many individual parts of the software process.

It is considered to be strongly advisable, therefore, for NASA to undertake a thorough review of the software generation process. The objective of this process is to determine whether the process can be simplified, made more efficient and productive, and more simply and effectively integrated and controlled.

SPACE SHUTTLE MAIN ENGINE (SSME)

(Ref: Findings #5, 6, 7)

The SSME program has made considerable progress during the past year. A particularly noteworthy achievement is the fact that there were 13 flight engines available at KSC at year's end. This provides a ship set for each of the

Orbiters plus a supply of four spare engines. The stand down for the hydrogen leak problems encountered in mid-1990 contributed to the production catch-up. Four more engines are to be delivered during the first half of 1991; three of the engines are for OV-105, Endeavour.

The "engine room" at KSC has been upgraded so that all post-flight and pre-installation checkouts of engines can be performed there in their entirety. The operating plan that has been adopted is to routinely remove all three engines after a flight and to perform the post-flight inspections in the engine room. This avoids interference from or with Orbiter tests. When the Orbiter is ready to receive its engines, a spare set will be installed. This will expedite the turnaround of a Shuttle.

The development of safety-enhancing SSME modifications described in last year's report has made significant progress in some areas and has run into difficulties in others:

<u>High-Pressure Oxidizer Turbopump (HPOTP)</u>: The monoball bearing housing on the pump end of this machine did not prove to be satisfactory; excessive bearing wear was encountered during tests. The project has opted to discontinue effort on this modification and return to the original pump-end configuration while retaining the changes to the turbine-end, the latter having proved to be satisfactory. This configuration has to be certified in a test program.

The HPOTPs are now being reflown on the basis of the data from the in-flight "health-monitoring" strain gages installed on weld #3. It is anticipated that three flights can be achieved before the need for a tear down to replace the pump-end bearings. The design modifications to the turbine-end of the turbopump have yielded test results that indicate that the turbine-end can be operated safely for six flights. Based on these facts, the project has decided to operate the HPOTP in the following manner: (1) after three flights, the pump end only will be torn down to replace the bearings; and (2) after six flights, the entire machine will be disassembled and refurbished. Tearing down the pump end only and refurbishing it requires only 4 to 6 weeks vice 12 weeks for doing this to the entire machine. This will significantly improve the logistical situation for the HPOTP. Certification testing is the pacing item for this new configuration and is in process. It is anticipated that the testing will be complete in April 1991.

<u>High-Pressure Fuel Turbopump (HPFTP)</u>: The safety modifications described last year have proven satisfactory in test. Formal certification testing has been completed. There remains only to accumulate 10,000 seconds of operation on the four other units in the test program to clear this turbopump configuration for flight. All pumps that are to be delivered after the first quarter of March 1991 are planned to be of this configuration. It is expected that this turbopump will be limited to about eight flights between tear downs.

<u>Gaseous Oxygen Heat Exchanger</u>: The External Heat Exchanger development has been cancelled. It was not possible to develop a process to fabricate platelets of flight quality. The single tube heat exchanger is now the selected approach. The process to fabricate the long tube has been demonstrated and a full-scale heat exchanger is being manufactured.

<u>Two-Duct Powerhead (Phase II+)</u>: This modification demonstrated the flow pattern and pressure drop improvements

desired in its test. Unfortunately, the changes caused an adverse effect on the main combustion chamber, wall cracks occurred much sooner than they had with the three-duct powerhead, and injector baffle and injector face erosion were encountered as well. It is believed that changes in the injector shield design details resulted in a reduction of the film coolant flow leading to the phenomena experienced. The design of the flow shields is being modified so as to restore the film coolant flow at the injector ring-seal to its former level. If successful, it is planned to introduce this powerhead along with the single-tube heat exchanger.

Block II Controller: Hot-fire testing of the new controller is in process at Stennis Space Center. About 17,000 seconds of successful operation has been accumulated on six units as of the date of this writing. The flight software is in development and will be tested on engines in early 1991.

Single-Crystal Turbine Blades: Work on this modification has been put on indefinite hold. The rationale is that the Alternate Turbopump Program uses this material, and incorporation of such blades in the Rocketdyne turbopumps could probably not be accomplished before the ATP machines become available.

High-Pressure Fuel Duct: High-pressure fuel ducts made of INCO 718 instead of titanium have completed testing satisfactorily. The titanium duct had exhibited a tendency to crack at its flanges, which led to mandatory dye-penetrant inspections for cracks within 45 days of launch. This complicated launch support and made it a critical schedule item. The new ducts will be phased in as the hardware becomes available. This is now estimated to occur from late 1990 through mid-1991.

Alternate Turbopump Development Program: A number of design problems have surfaced during tests of both the fuel and oxygen units. Fixes have been designed and are being incorporated with attendant schedule slips. Testing on the component test stand at P&W has proceeded quite slowly. Only about 25 percent of the test attempts have gone to completion. This is a low success rate even for a facility of this type. The most recent schedule indicates the start of engine-level testing of the fuel turbopump on an engine employing a Rocketdyne oxygen turbopump in January 1991. This must be regarded as very optimistic.

Large-Throat Main Combustion Chamber: The timing of the potential incorporation of this chamber is uncertain as it has been linked to the Advanced Fabrication Program whose objective is to apply new fabrication techniques and processes to the manufacture of the main combustion chamber and nozzle. Development of such processes is always fraught with unexpected technical difficulties so schedules are even more prone to slips than other types of development activities.

The large-throat main combustion chamber has been tested on two different test stands at Stennis. Combustion stability tests showed no indication of instability during eight test series over the operating range. There were significant reductions in speeds, flows, pressures, and temperatures as had been predicted. All of these changes serve to reduce the engine environment to which the several components (particularly the turbomachines) are subjected. This increases the operating margins of these devices significantly. The issue that remained last year, that is the specific impulse, has been resolved by the tests at Stennis. Engine 0208 demonstrated an Isp of 452.47 seconds, about minus 1 sigma of the values of the last 15 engines tagged. The concern about performance of the large-throat main combustion chamber should be laid to rest.

As is evident from the above, the SSME program has made notable progress since last year. All the evidence points to the fact that the engine is maturing and, barring unforseen problems, will soon provide reasonable numbers of reuses between overhauls, albeit lower than had been targeted originally. It is regrettable that the large-throat main combustion chamber, which increases the margin of safety, was not given higher priority in the safety and reliability enhancement modifications development program.

SOLID ROCKET MOTOR (SRM)/ SOLID ROCKET BOOSTER (SRB)

(Ref: Finding #8)

The present Solid Rocket Booster requires a waiver to permit the use of the aft skirt with a Factor of Safety of 1.28. Such waivers have to be processed for each flight. To increase the Factor of Safety, the spherical bearings at the hold-down posts have to be biased radially. Even with this process, the aft skirt does not meet the 1.4 Factor of Safety. Thus, a waiver is required.

The Advanced Solid Rocket Booster is a new Solid Rocket Booster that will take many years to design, test, and build. It is prudent and safer to eliminate the need for "routine waivers" and the biasing procedures, and design an aft skirt with a 1.4 Factor of Safety.

(Ref: Finding #9)

The current Redesigned Solid Rocket Motor manufacturing, test/checkout, and assembly operations (cases, nozzles, propellant fill, etc.) have shown a vast improvement over the past several years. Efforts are continuing at Thiokol to enhance these operations through additional automation and procedural upgrades. Such improvements result in far less "touch" labor and thus a lowered probability of human errors. Management has shown that with proper effort, a spick-and-span site can be provided and maintained for critical manufacturing steps for the Solid Rocket Motor.

(Ref: Finding #10)

The planned concurrent use of both the Advanced Solid Rocket Motor and the current Redesigned Solid Rocket Motor at KSC raises a number of issues that must be addressed at this time to ensure that nothing is dropped through the crack during mission preparation and conduct. Among the concerns that must be addressed:

- Each Advanced Solid Rocket Motor/Advanced Solid Rocket Booster and Redesigned Solid Rocket Motor/Redesigned Solid Rocket Booster will require varying numbers of different tools, facilities, and procedures.

- The personnel trained to accomplish the test/checkout, stacking, and associated processing tasks will have to be trained for the two different sets of assembly procedures and interfaces with the rest of the Space Shuttle stack.

- Extreme care must be taken in the two sets of assemblies for configuration control and management requirements, waivers, exceptions, and other activities. Management through engineering to the hands-on organizations will have to exert exceptional vigilance to preclude mix-ups.

- Because the Solid Rocket Motor cases and other components are reusable, positive steps are required to ensure spares, maintenance, and overall logistics can support this two-fold challenge.

- Each mission will have to be sure that the proper inputs of Advanced Solid Rocket Motor/ Advanced Solid Rocket Booster or Redesigned Solid Rocket Motor/Redesigned Solid Rocket Booster performance and physical characteristics are used in the design of the mission and the software for launch processing and firing room.

(Ref: Finding #11)

The Advanced Solid Rocket Motor Development and Verification Test Program is well planned; however, tests may produce results that are not expected and understood.

It is necessary, therefore, to plan for contingencies, especially for those items of design for which uncertainties remain.

In particular, the scaleup of Propellant Continuous Mix Process from experience based on a Pilot Program to a full-scale Advanced Solid Rocket Motor may be very difficult and may warrant an alternate plan.

It is important that the entire Test program be maintained and not be the target for "cost savings".

To accept the design as safe and reliable, NASA should understand how the design behaves throughout the range of conditions that the Advanced Solid Rocket Motor will experience.

Tests should be instrumented to validate analytical models and verify that the design meets the requirements and also how the design works.

For each test, the team must make analytical predictions of the performance of the test article and deviations must be explained.

(Ref: Finding #12)

The automation being developed for the Advanced Solid Rocket Motor is ambitious. Areas of uncertainty include:

- <u>Stripwinding</u>. This has been done before for the outside of a cylinder, but not for the inside.

- <u>Hydrocleaning</u>. Except for sensing, the satisfactory completion of the job is another matter.

- <u>A Continuous Propellant Mixing and Casting</u>. Such a process of this size has never been attempted.

(Ref: Finding #13)

The T-97 Solid Rocket Motor Dynamic Test Stand Facility located at the Thiokol, Wasatch, Utah plant is unique because it can apply simulated flight loads to the Solid Rocket Motor during a full-scale firing. This facility plays an important role in assuring continued flight worthiness of the Redesigned Solid Rocket Motor. The T-97 stand is highly instrumented, and along with its control center and photographic equipment, is needed for continuous support of the Redesigned Solid Rocket Motor program. The basic concrete and steel foundations and support structures are quite massive to enable the measurement of more than 2- to 3-million pounds of thrust.

Moving this massive facility to a distant new site and reconstructing it is in itself an imposing and time-consuming job. A new facility should be constructed for the Advanced Solid Rocket Motor Program at the Stennis Space Center.

EXTERNAL TANK (ET)
(Ref: Finding #14)

The external tank has been relatively trouble free. External insulation divots that have peeled off with no apparent detrimental effect on the Orbiter continue to occur, but with reduced frequency. Instrumentation concerns are being taken care of in a manner that continues to provide safe support to Space Shuttle missions.

A visit to the Michoud Assembly Plant where the external tanks are manufactured and stored for a period before shipment to the KSC was very encouraging. Dedication to product quality and rapid response to issues as they arise was apparent. Martin Marietta and NASA are also to be complimented on their TQM programs.

LAUNCH AND LANDING OPERATIONS
(Ref: Findings #16, 17, 18)

The commitment of NASA to seek and find the "leaks" on STS-35 and STS-38 is an excellent example of "safety first, schedule second". NASA was under tremendous pressure during the summer of 1990 to "get something off the ground," but they remained steadfast in their commitments and did not succumb. The launch rate is ever changing with the budget and times. NASA should maintain their posture of first being safe and allowing the schedule to follow.

Streamlining the launch processing activities at KSC has been the focus of much attention for many years. Prior to the Challenger accident, many steps were taken to streamline processing without affecting safety. Since the Challenger accident, many changes were made to the processing flow with greater emphasis on inspections, test checkout, and launch constraints.

Over the past 2-1/2 years, a number of teams have been formed at NASA Headquarters, KSC, JSC, and Marshall Space Flight Center (MSFC) to examine the steps required to ensure safe launch and landing of the Space Shuttle. They have examined both ground facilities and the way they are used as well as flight hardware and the way they are tested. This work continues today, and strides are being made, but much more needs to be accomplished to reduce paperwork, the large number of procedures, and tests. From everything the Panel has seen and heard, NASA and their contractor organizations are doing thorough safety-minded reviews.

Each year, beginning with the annual report released in January 1983, the Panel has examined the procedures, practices, capabilities, and general working environment surrounding the processing of the Space Shuttle at KSC in preparation for flight. Given the hundreds of thousands of discrete actions that must be taken in each turnaround cycle and the criticality of many of these actions to flight safety, the Panel viewed the responsibilities of NASA and the Shuttle Processing Contractor (Lockheed Space Operations Co.) as among the most important and challenging in operating the Space Shuttle. As these prior annual reports have made clear, we concluded that NASA and the Shuttle Processing Contractor recognized the criticality of these functions and were committed to accomplishing them successfully. At the same time, we also continued to scrutinize management practices and launch processing activities as they relate to safety. Although many of our concerns have been addressed, launch processing remains an area of the Panel's concern.

Launch processing at KSC is being accomplished with a declining "incident" rate. Statistics provided to the Panel by the Shuttle Processing Contractor indicate that 99.998 percent of the "work steps" are completed without incident, driving the incident frequency rate down to 0.9 incidents per 200,000 work hours. In most enterprises, this level of success, if not an artifact of the reporting system, would be seen as entirely satisfactory. If valid, it represents real progress by NASA and the Shuttle Processing Contractor from earlier periods. Nonetheless, in an operation as sensitive and complex as the Space Shuttle, a single error in an otherwise flawless operation can result in catastrophe. For this reason, the goal of achieving "zero incidents" in launch processing seems entirely appropriate.

As part of its continuing oversight, the Panel reviewed the current situation with NASA/Shuttle Processing Contractor management and with "hands-on" personnel (engineering, quality control, and technicians). The Panel's conclusions are similar to those reached in two independent efforts: "Assessment of Human Error Incidents at KSC," October 1990, by former astronaut John Young, currently assigned to special projects in the Shuttle Program; and the report of the "NASA/Shuttle Processing Contractor Committee to Study Incidents," July 1990, headed by J. A. (Gene) Thomas, now Deputy Director of KSC. In addition, many of the points made in these two reports also were cited in the report of the Atlantis (OV-104) Fuel Cell Mishap Investigation Board.

The concerns expressed in these reports parallel the findings and recommendations of the Panel, as expressed in earlier annual reports and as determined in our most recent discussions at KSC (October 1990). These concerns must be considered from the perspective of the dedicated and overall successful effort being made by NASA and the Shuttle Processing Contractor to safe launches of the Space Shuttle.

The Shuttle Processing Contractor seeks to prevent human error by strict, pervasive, and formal accountability. This is clearly a necessary component of Shuttle launch processing. However, achievement of this objective need not impair other desirable attributes such as having a system that consciously seeks to make the most of the skill, experience, and positive motivation of the work force. In some cases, we encountered perceptions of strained relations between hands-on workers and various levels of management.

Communication among engineers, technicians, and quality control personnel, although improved from earlier years, continues to be a problem in some situations. The accuracy of work instructions generally has improved, but errors are still encountered. Likewise, training has improved but in some cases the hands-on knowledge of the instructors could be upgraded. Most of the logistics problems and severe shortage of spare parts have been resolved, although special efforts are still required (and are being made) to retain parts availability from certain original equipment manufacturers and to improve the repair turnaround times of Line Replaceable Units (LRUs).

Despite well-publicized disappointments in 1990, NASA and the Shuttle Processing Contractor are launching the Space Shuttle successfully and safely. However, the work environment at KSC needs greater management attention to continue moving towards one that minimizes the potential for human error today and in the future as the flight rate increases. The goal of "zero incidents," although extremely difficult to achieve, must nonetheless be the driving force of KSC management and the Shuttle Processing Contractor.

"Waivers" are defined as a written authorization to accept designated items which, during production or after having been submitted for inspection, are found to depart from specifications, but nevertheless are considered suitable for use "as is" or after rework by an approved method.

It would appear, that at this time the world of waivers might well benefit from a concentrated review; and where necessary, appropriate specification changes should be made to eliminate the need for repetitive waivers.

MISSION OPERATIONS
(Ref: Finding #19)

When the Mission Control Center was first activated in the early 1960s, it was considered a technical marvel. However, this original architecture has received only modest upgrades since the Apollo Program days. Until recently, it maintained a single mainframe based architecture that displayed data and largely left the job of data analysis and trend determination to the flight controller teams monitoring the consoles. The display technology utilized in this system is monochrome and primarily displays text information. The job of turning data into information upon which flight decisions could be made is performed by the controllers through interpretation of the incoming numeric data. In cases where it was determined that additional computational support was required, small off-line personal computers were added. The controllers manually copied data from the console display screens and entered it into the small computers to perform off-line analysis.

Although this system is technologically outdated, it contains years of customizing efforts and has served NASA well through Space Shuttle Program missions to date. Several factors are now driving NASA to change the architecture of the Mission Control Center operations. First, the primary reason seems to be to control costs. Second, automation available today can be used to expand the capabilities of controllers by eliminating some of the data reduction tasks they must perform and by increasing the amount of information they can utilize in making decisions. Third, the time required to obtain information for decision-making can be substantially reduced. Finally, there is continuing concern over the loss of corporate knowledge due to retirements and personnel turnover in conjunction with hiring freezes.

These factors have resulted in efforts by NASA to utilize the present generation in engineering workstations, on-line real-time expert systems, and traditional automation to allow flight controllers to perform more tasks and to capture the corporate knowledge of senior personnel. A prototype system called the Real-Time Data System has demonstrated the feasibility of achieving new levels of decision support. The Real-Time Data System also provides a technique to isolate applications so that new applications can be added without endangering the previously established base of flight critical code.

This Real-Time Data System effort, for example, has resulted in the ability to have a graphic display of a number of engine parameters as a function of time into flight. Further, key flight parameters can be displayed in easily read formats with color used to convey criticality. Previously, the engine data was displayed in tabular form, and the flight controllers had to apply mental gymnastics to determine what was happening. The key parameters were displayed only in code, and the flight controllers had to mentally convert these to their actual meanings. Moreover, the new technology is capable of obtaining and displaying this more easily used information up to 4 seconds faster than the old control room computers.

Thus, as described to the Panel, the advances in workstations and real-time expert systems have enabled small programming teams to implement new real-time data reduction techniques that have made major improvements in NASA space operations. Unfortunately, now that the basic capabilities have been demonstrated, they are not being incorporated into the flight control system in a manner that optimizes productivity. For example:

- The fact that the Real-Time Data System is 4 seconds faster than the mainframe is good only if the Real-Time Data System is the decision-making system. At present, it is not. When both systems are used simultaneously, as is presently done, a 4-second difference between the two systems (old and new) could actually cause an operational problem because of the time lag between the Real-Time Data System and the older system that is used for decision-making.

- There does not appear to be any discipline imposed with respect to which system is used. It appears that the older, more experienced flight controllers, prefer the current mainframe/ monochrome system while the new controllers prefer the Real-Time Data System color workstations. Established policy is to make all decisions (calls) using the old, slower system. Controllers, therefore, have access to two sets of information from the same source but displayed in different formats and with a 4-second time lag. The use of such things as "notes taped on the consoles" is not an adequate replacement for appropriate management control or an orderly process for the introduction of change.

- The way in which the two systems are being used may actually increase console operator workload. The scan patterns required to see both the old and the new displays becomes very complex. The very fact that two screens are available at the same console can cause difficulties during times of stress.

- Having color, graphics workstations emulate the old displays wastes much of their capability. The displays must present a large and potentially bewildering amount of information to the controller and, therefore, could benefit from human factors/ performance-oriented inputs.

- One of the inherent benefits of the new technology used in the Real-Time Data System is the ability to calculate and display trend information. In some situations, the availability of trend information can be invaluable because it increases the time available for decision-making. Greater incorporation of various projection and trend analysis in the design of the Mission Control Center would likely be very helpful.

The Real-Time Data System has demonstrated some excellent concepts, and the control room certainly could benefit from updating. However, the Real-Time Data System has reached the stage of development at which a more structured plan for utilizing its capabilities should be followed. This plan should include:

- A requirements analysis of the operations including work flows and task analyses.
- A human factors analysis of the interface to determine the best display formats, while taking into account: current controller experience and expectations, transition and initial training requirements, information transfer rates, minimization of response time errors, and fatigue.
- A comprehensive test plan with acceptance criteria.
- A phase-in transition plan.
- Off-line testing with simulations.
- On-line testing in parallel with current system.
- An upgrade to provide for the inclusion of new technology and to compensate for future obsolescence.

At the completion of the above program, a new Mission Control system based upon the new workstation/expert system technology should be phased-in to replace the existing Mission Control Center.

ASSURED SHUTTLE AVAILABILITY PROGRAM

(Ref: Finding #20)

The many Space Shuttle flights over the past few years has yielded a much clearer understanding of the significant risks and margins of safety built into the current Shuttle system. The Congress took note of this in the House Multi-Year NASA Authorization Bill of 1989, which authorized funds for specific safety enhancements. NASA responded to this with a report "Space Shuttle Safety Enhancements" October 1990 to the United States House of Representatives and the United States Senate. The Panel has recommended that the Space Shuttle Program implement an organized, visible, and well-funded program of safety and reliability improvements for the Assured Shuttle Availability Program.

Now NASA has a program with the same title, Assured Shuttle Availability Program, but with a somewhat different focus, that is, life extension and elimination of obsolescence. While both are worthy objectives, they do not necessarily encompass those changes and updates required for the enhancement of safety and reliability. Further, the use of the same title covering two somewhat different sets of objectives can, and probably will lead to confusion and misinterpretation. It is the Panel's contention that there should be two programs. One should emphasize significant safety and reliability improvements, the second should deal with such things as reduced turnaround time between missions, higher levels of performance, and life extension. Priority should be given to risk reduction.

Many of the "Typical Space Shuttle Safety Enhancements" list items noted in the Panel's March 1989 Annual Report have been or are being developed for incorporation into the Space Shuttle systems. This is very encouraging and should be continued. This applies to such items as the improved APU, the SSME alternative turbopump hardware, the so-called "10K" high-pressure pumps, the new general purpose computers, more reliable instrumentation, structural "beef-up" of the Orbiters, and upgrading of KSC facilities.

All Space Shuttle elements should maintain a continuous study to identify those modifications that would provide risk reduction.

LOGISTICS AND SUPPORT PROGRAM
(Ref: Findings #21 through 25)

The logistics and support program for the Space Shuttle is continuing to develop. The problems that persist, in general, are well documented and understood. They do, however, need continuing attention if flight rates are to be maintained without compromising safety.

1. Integrated Logistics Panel (ILP) Activities

The Integrated Logistics Panel meetings appear to be expanding their effectiveness as a principal management tool for the coordination of logistics issues across all Space Shuttle elements. The Integrated Logistics Panel also is watching the OV-105 developments at Palmdale to ensure smooth integration of that vehicle into the fleet. The quarterly meetings rotate among the involved NASA Centers. They are chaired by JSC with KSC as a deputy chair function. Ad hoc sessions also are held at various locations for specialized purposes, and internal logistics audits are encouraged. The Integrated Logistics Panel concept seems to be working well and provides a forum for coordination among contractors and between the contractors and NASA. ASAP believes this process is crucial to the control of the necessarily extensive Space Shuttle logistics support program.

2. NASA Shuttle Logistics Depot (NSLD)

Development of the NASA Shuttle Logistics Depot, which is located in Cocoa Beach and operated by Rockwell, is proceeding very satisfactorily, and should provide overhaul and repair facilities for a large range of Shuttle components when it is fully developed and equipped. The main facility encompasses some 223,000 square feet, and an adjacent group of smaller buildings has 45,000 square feet. Among its several aims, the facility will permit more rapid turnaround of Line Replaceable Units, reduce spares inventory requirements, and provide insurance against the cessation of Original Equipment Manufacturer (OEM) overhaul services for certain obsolescent and unique components. The manufacture and repair of some items of Ground Support Equipment (GSE) also is being provided for, and the entire facility will form a very well-equipped "back shop" for the on-site support of the Shuttle programs. Completion of the required shop equipment, availability of fully trained personnel, provision of technical manuals, support, etc., for the overhaul of a chosen component earns a "certification" to perform the task. To date, some 100 certifications have been obtained involving 3,255 Line Replaceable Units. At present, the plan calls for 230 certifications to be valid by FY 1994 involving 3,795 Line Replaceable Units.

3. The Thermal Protection System (TPS) Manufacturing Facility

The nature of repair and replacement of elements of the Orbiter TPS led to a decision several years ago that this could best be performed on-site at KSC rather than remotely on the west coast.

The tiles presently are being made by Lockheed (west coast) and Rockwell at KSC. They are not now being carried as spares owing to fitting problems and, therefore, are being machined individually to suit each application. The flexible blanket replacements are handled similarly, and some of the thermal barriers also are made on demand, although a few are carried as spares. Some 7800 tiles, blankets, gap fillers, etc., have been manufactured or processed through the Thermal Protection Systems Facility at KSC during 1990. Development of the remaining equipment and staffing needs appear to be on target to completion in 1992.

4. Logistics Management Responsibility Transfer (LMRT)

The Panel previously has commented upon the activities of the Logistics Management Responsibility Transfer program and has noticed, with approbation, the repositioning of experienced management and other skills from the west coast to the KSC area, particularly with respect to the NASA Shuttle Logistics Depot facility at Cocoa Beach and the Thermal Protection Systems on-site facility at KSC. This Logistics Management Responsibility activity also is continuing on a broader front. A memorandum of agreement recently has been completed for issues affecting SSME logistics between KSC and MSFC.

5. Control and Communication Systems - Logistics

Systems for the control of the huge inventory and dollar amounts necessarily involved in the entire Shuttle logistics support system have grown with time and, it is hoped, are now near maturity. The root of these systems is to be found in the now well-established Program Compliance and Assurance System (PCASS), which currently is being augmented so that it will meet its design goals. The Integrated Management Information Center (IMIC) and the Meeting Support Environment (MSE) have been introduced. A file server will be installed at all sites enabling the Integrated Logistics Panel presentations to be viewed. All the logistics data requirements, e.g., specifications, maintenance manuals, etc., for the entire Shuttle system are collected under a series of document trees for easy retrieval. A logistics supportability alert system is being introduced to advise of major issues such as pending loss of suppliers and receipt of bogus parts. The alerts will be contained in the PCASS.

6. Cannibalization

Previous Panel reports have reviewed this important aspect of Orbiter vehicle safety and have observed the implementation of satisfactory control programs to keep cannibalization. The principal control measure is the restriction of component removal actions to those that are absolutely required. There also has been a change in the definition of cannibalization, which tends to artificially suppress the apparent cannibalization level.

The overall situation of cannibalization can be generally described as "reasonable" or "normal." Quite obviously, "zero canns" continues to be the goal to the extent that it is cost effective. Continuing to watch the rate of cannibalizations will provide NASA management with critical information on which components may be in short supply or might productively be the subject of life extension activities.

7. Component Repair Turnaround Times (RTAT)

The total elapsed Repair Turnaround Time still can be excessive with a resulting major impact on inventory management. There are several contributing causes for this that were discussed briefly in the 1990 Annual Report (p. 50), but one of the key issues is the average time involved in the engineering analysis of failed components. The overall trend of Repair Turnaround Time showed a significant improvement toward the end of the year, but in some cases, notably the components overhauled by the Original Equipment Manufacturers, is much too high. Management emphasis currently is being directed to the entire problem of reducing Repair Turnaround Time and should continue.

8. Out-of-Production Parts

Some of the Original Equipment Manufacturers are not providing sufficient support for out-of-production parts. NASA and its contractors have evolved good systems for identifying and tracking these problems, but the difficulties of ensuring continuing production with small batches of obsolescent or semi-obsolescent parts inevitably will increase with Orbiter age. The problem involves balancing the alternatives of purchasing and storage of excess parts, establishing manufacturing facilities and skills at KSC, or potentially facing critical shortages. The heart of the problem is that many manufacturers simply do not want to devote any more manpower or effort to revive production. The study of possible alternative source vendors for critical vendors continues but is necessarily a slow and complex process.

9. Scheduled Structural Overhaul of the Orbiter Fleet

NASA's response to the 1990 ASAP Annual Report concerned with structural overhaul (p. 51) dealt principally with the visit on OV-102 at the Rockwell Palmdale facility scheduled to begin in June 1991. A review of the major modifications necessary to bring OV-102 up to the standard of OV-105 was included. During the work on OV-102, a "3-year" and a "6-year" structural inspection will be performed. It is assumed that this will provide the information necessary to define a basic structural overhaul program. This program would then be fitted into available intervals in the launch program up to 1995 for all four Orbiters.

A second element of longer term maintenance program planning has been defined but apparently is not presently funded. It is known as "Orbiter Supportability Plan - Project 2020" and is intended to provide a basis for ensuring a rational program for orderly maintenance and support of the fleet through the assembly of the SSF. The outline of the plan properly embraces the interfaces of the existing major contractors and the operating NASA Centers, and outlines an organizational support formula. This formula includes detailed Line Replaceable Unit supportability and full structural integrity accountability. The ASAP has an interest in seeing this program go forward as planned.

10. Automatic Test Equipment (ATE)

The development of ATE and the recruitment of the necessary computer and engineering skills at the NASA Shuttle Logistics Depot is a valuable undertaking. The installation of the Hewlett Packard automatic test station and the two program development stations in the Cocoa Beach facility is praiseworthy. The eventual aim is to test 60 different Line Replaceable Unit types, including multiplexers/demultiplexers (MDMs) that tend to be troublesome, and to replace some 30 special purpose systems with automatic procedures. With full maturity, and perhaps later expansion of this medium, it is reasonable to expect much more rapid turnaround of difficult Line Replaceable Units as well as a more thorough and reliable individual test regime.

11. Advanced Solid Rocket Motor Logistics Program

An early start on logistics programs for the Advanced Solid Rocket Motor has been made, and includes the delineation of the support requirements for testing the 48-inch motors at MSFC. Shipping containers and transportation methods have been established for all elements, e.g., exit cones, nozzle assemblies, cases and segments, and the 48-inch motors. Raw materials logistics for the Advanced Solid Rocket Motor production have been similarly provided for.

B. SPACE STATION FREEDOM PROGRAM

(Ref: Finding #26)

The Space Station Freedom Program is currently undergoing redesign; therefore, no specific comments are offered. However, there are lessons learned that merit consideration.

- NASA should take a broader, longer term approach to the requirements for specific flight computers. The redesign efforts under way for Space Station, together with studies in progress in one of its research laboratories and the need to start planning now for the next change in Space Shuttle computer systems, make this a good time to consider changing the approach.

  NASA should embark upon an agency-wide, long-range plan for computer upgrades in long-term space programs. This should include not only hardware development, but software and testing issues as well.

NASA should utilize efforts already under way in its Ames Research Center and make the effort an intercenter one, with use of the results, to the extent possible across the agency.

- NASA began development of a Technical and Management Information System (TMIS) as part of Space Station. While the ideas behind this system were laudable, it rapidly fell short of its promise largely through late deliveries. Nevertheless, many of the tools planned for the Technical and Management Information System are of general value to NASA and could be used on any project, not just the Space Station. If fully implemented with proper participation of users throughout NASA and if adopted across the agency, Technical and Management Information System could make integration of activities across Centers much easier as well as providing better support structure to project management.

C. AERONAUTICS-OPERATIONS

AIRCRAFT OPERATIONS
(Ref: Finding #27)

The Panel has for several years been concerned that NASA top management has not given adequate attention to matters of aircraft operations and aviation safety. One reason for the apparent lack of a common NASA-wide policy covering these activities is the diverse nature of NASA's aircraft uses. These fall into three categories: (1) research aircraft such as the X-29, (2) support and training aircraft such as the 747 Orbiter transport and the T-38s proficiency airplanes, and (3) administrative aircraft, i.e., the gulfstream for personnel transportation.

Frequent changes in Headquarters management and preoccupation with more intense issues has procrastinated decision-making in this area. However, based on recent discussions with the Administrator, the Panel has been requested to make a thorough study of these matters and to examine in detail the functions and responsibilities of the various Headquarters organizations involved, including the Intercenter Aircraft Operations Panel (IAOP). As regards to the Intercenter Aircraft Operations Panel, a Panel member has been appointed to attend its meetings and any other meetings dealing with aircraft operations and aircraft safety matters.

With this encouragement and mandate to examine the full range of NASA flight operations, it is believed that many of the concerns expressed in the past can be resolved.

RESEARCH AND TECHNOLOGY
(Ref: Finding #28)

The X-29 flight test program has been reviewed periodically by the ASAP since 1984. This aircraft incorporates advanced and unique aerodynamic, structural, configurational, and fly-by-wire flight control technology. With such a large number of untried technologies being flown for the first time, the safety risks have been high, and NASA has managed the program with a high priority placed on safety. By the end of the year, the two X-29 experimental aircraft had completed over 250 flights. The principal efforts were directed towards clearing the aircraft for its maximum speeds, mach number and altitudes, and for gathering data during high alpha maneuvering flight. The current flights of the second aircraft have been aimed at exploring various high alpha maneuvers (to levels greater than those demonstrated in the wind tunnel) and to evaluate the handling qualities during these severe flight conditions. Wind-up turns and asymmetric maneuvers have been accomplished. The software of the control laws has been undergoing a series of modifications to improve the flying qualities and the higher angles of attack capabilities.

The ASAP reviewed a number of research programs that have the potential for enhancing aviation flight safety. These included wind shear detection and warning, hazards of lightning strikes, heavy rain effects, aging commercial aircraft and airframe structural integrity, take-off performance monitoring, fault tolerant electronic controls, and activities to assist the air traffic control function by studying terminal approach and landing ground and cockpit concepts. The results of these types of programs will increase in importance as commercial air traffic continues to increase.

D. SAFETY AND RISK MANAGEMENT

MISSION SUPPORT
(Ref: Finding #29)

The fault tree analysis approach is a deductive analytical technique that supports detailed systems analyses, provides clear inputs for decision-making, and provides a rationale basis for communications. When used as a system safety analysis tool, as it was during the later stages of the hydrogen leak investigations in mid-1990, the fault tree highlights the interrelationships of those system events, which may result in the occurrence of an undesired event — in this case, the hydrogen leaks.

The fault tree approach combined with Failure Modes and Effects Analysis has the ability to help resolve significant problems that initially may elude traditional engineering solutions. It is logical and turns over "every stone" in the process of determining casual relationships within a system.

All engineers involved in any aspect of design, test, or operations of any aerospace system should be given at least a minimal grounding in these valuable tools.

TOTAL QUALITY MANAGEMENT (TQM) OBSERVATIONS
(Ref: Finding #30)

Over the years, there have been numerous "packaged" approaches to quality improvement. Some have worked, most have not. Often, these techniques have been little more than fads whose appeal faded when they did not turn out to be "miracle cures" for all management problems.

The Panel has been briefed on TQM activity at NASA Headquarters, NASA Centers, and NASA contractors, and there is no doubt that a great deal of enthusiasm is being attached to TQM. As often stated by TQM practitioners, results only will be achieved over a period of years and then must be sustained thereafter. Based on the material presented to the Panel, many of the TQM efforts were not in the mainstream of the ongoing work. There appears to be a need to bring the effort down to those who do the "hands-on" work. This includes the engineers, test personnel, technicians, schedulers, and quality assurance/inspectors. It is certainly essential to have the senior management throughout the organization involved, but the enthusiastic and practical day-to-day implementation of TQM philosophy needs nurturing at the hands-on level. There does not appear to be enough of this going on.

To meet the goals of TQM, it would be well to have additional attention given to the means by which the hands-on personnel can be made an integral part of the overall TQM activity. This includes having senior and middle management make it their business to get out onto the floor and provide a sincere effort to both understand and support the floor personnel.

TQM, by itself, is not a solution to quality problems. It is, however, a potentially effective amalgam of some of the latest techniques for fostering group interaction and team-building. If used as a tool by a concerned management dedicated to improving operations, TQM appears to be very effective. On the other hand, if it is imposed by management without adequate involvement or follow-up, it may be ineffective or even counterproductive. The aviation press over the past year has contained numerous references to the extensive problems experienced by one major contractor as a result of an over-zealous TQM program.

By far the most impressive TQM implementation seen by the Panel was the one at the Michoud Assembly Facility. This model program has generated significant enthusiasm among the personnel at the facility and has yielded impressive productivity improvements. NASA would do well to learn from this success and attempt to transfer it to other facilities by directly involving the Michoud staff responsible for their TQM program.

SAFETY REPORTING SYSTEMS
(Ref: Finding #31)

Accidents and near-misses or incidents are rarely the result of single causes. Rather, causation typically can be traced to a relatively complex combination of factors such as design defects, component malfunctions, and human errors. Therefore, the most effective accident and incident investigation techniques rely heavily on a multi-disciplinary approach combining investigators trained and experienced in the hardware, software, institutional, and human performance aspects of the involved system. This approach, perhaps, is exemplified best by the accident investigations conducted by the National Transportation Safety Board (NTSB).

NASA's Management Instruction on "Mishap Reporting and Investigation" provides a basis for investigating accidents and incidents, and acknowledges that human factors might be needed in some investigations. In fact, however, it may require initial analysis by a trained human factors specialist to determine if human performance considerations were germane to the incident. Since the vast majority of NASA's operations involve complex human-machine systems, it is reasonable to include a human performance specialist in the initial review of all serious incidents. This will help to determine the role that human error played in the incident and to identify the cause of any errors identified. This is consistent with the need to conduct accident and incident investigations with the objective of determining cause as well as responsibility.

Before lessons can be learned from an accident or incident, it must be brought to the attention of those responsible for investigations. Accidents and incidents with the potential for serious consequences are typically reported and, therefore, can be investigated in some detail. Incidents and close calls that do not result in injury or property damage, however, often go unreported even if they have the potential for serious loss or sufficient visibility to commend and investigate. Therefore, a complete incident investigation system must include a provision for collecting data on events that did not result in a loss or sufficient visibility to command and investigate.

NASA maintains the NASA Safety Reporting System, which has the objective of collecting anonymous data on incidents. It is patterned after the highly successful Aviation Safety Reporting System NASA operates for the Federal Aviation Administration (FAA). While the NASA Safety Reporting System has generated some information, it does not appear to be getting the widespread use characteristic of the Aviation Safety Reporting System. One reason may be the absence of a "buffer" between the responsible agency and data collection source. People reporting to the Aviation Safety Reporting System know that they are not sending potentially incriminating information to the cognizant regulatory agency (FAA has jurisdiction and the reports are submitted to NASA). With NASA Safety Reporting System, on the other hand, NASA fulfills both roles. This may be somewhat daunting to a NASA or contractor employee whose career advancement may depend on maintaining an incident-free record.

In light of these considerations, NASA should carefully review the operation of the NASA Safety Reporting System to determine if it is maximally effective. This review might profitably reexamine the notion of having this program run by an outside, "neutral" agency in an attempt to increase its effectiveness.

E. OTHER

NASA FACILITIES
(Ref: Finding #32)

NASA's Research and Technology and Research and Development programs depend greatly on the availability and productivity of its many unique test facilities. Many of these facilities are more than 40-years old and are showing the wear and tear of these years of use. This is particularly true of NASA's aeronautical facilities, some of which had deteriorated to the point that they were considered unsafe. Others still employed their original operating and control equipment which, now, are technologically obsolescent and cannot be repaired because their components are no longer manufactured. Obsolescence similarly affects the instrumentation and data systems of the facilities rendering them inefficient and limiting their productivity.

Recognizing these conditions, NASA chartered a committee (the Hopps Committee) to assess the situation and to recommend a course of action. The committee reported in 1987 and recommended that major refurbishments be undertaken for many of NASA's facilities in accordance with certain priorities. Responding to this report, NASA developed a 5-year plan to revitalize the highest priority facilities.

This program focuses primarily on the aeronautical facilities, which are the agency's oldest. It addresses wind tunnels, their support facilities, and their data acquisition and control equipment. Activity began in FY 1989, and the pace is accelerating. By FY 1994, the bulk of the planned renovation/restoration of these highest priority facilities should be completed. But the current program does not cover all of the needed renovation/restoration. By the time 1994 arrives, the facilities that had been assigned lower priority in the 1987 assessment will have aged another 7 years and, undoubtedly, will have suffered further deterioration in both safety and operational adequacy. The revitalization program should be extended to accommodate the facilities that did not make the "first cut".

Not only should the major renovations be extended, provision also must be made in planning and budgeting for a continuing program of major maintenance activities so as to preclude the sort of deterioration and obsolescence that has been experienced. Experience has shown that it is frequently much easier to obtain funding to build a new facility than it is to obtain support to properly maintain an existing one. This is sometimes humorously referred to as the "edifice complex" and is endemic throughout our society. This must not be permitted to take root again for NASA's facilities.

NASA is to be commended for its facility revitalization program. Certainly, it was long overdue. Now is the time for the agency to provide for the extension of the program to other facilities and to incorporate a continuing major maintenance program so that the degree of deterioration and obsolescence experienced in the past will not recur.

EXTRAVEHICULAR MOBILITY UNITS/SPACE SUITS
(Ref: Finding #33)

The current Space Shuttle space suit is approved for up to three EVAs from the Space Shuttle before requiring maintenance. There are plans to extend this number to 12 and even 24 when the suit is used during assembly and support of the Space Station. The current suit also requires extensive pre-breathing periods, which are tiring for the crew and limit the available EVA work time. The proposed high-pressure suit designs eliminated or reduced the need for pre-breathing and were intended to be certified for extensive reuse before refurbishment.

It now appears that development of the high-pressure suit designs has been suspended due to lack of funds. Also, some astronauts do not appear to want the new suit because the current suit is more flexible and less restrictive of torso motion. Some astronauts also stated that pre-breathing requirements with the existing suit are overly conservative and could be reduced as there has never been a decompressive sickness problem with any EVA to date. Pre-breathing also could be reduced by lowering Space Station ambient pressures to 10.2 psi, but that would be counterproductive to many of the experiments that are to be carried since their results are referenced to sea-level experience.

NASA has spent considerable efforts this past year determining the amount of EVA activity that would be required to maintain the Space Station. The results were shocking. Much more EVA time would be required than would be desireable. It also was concluded that greater use of robotics and automation together with some redesign to make such automation possible could greatly reduce the predicted EVA time, and make the resulting time acceptable.

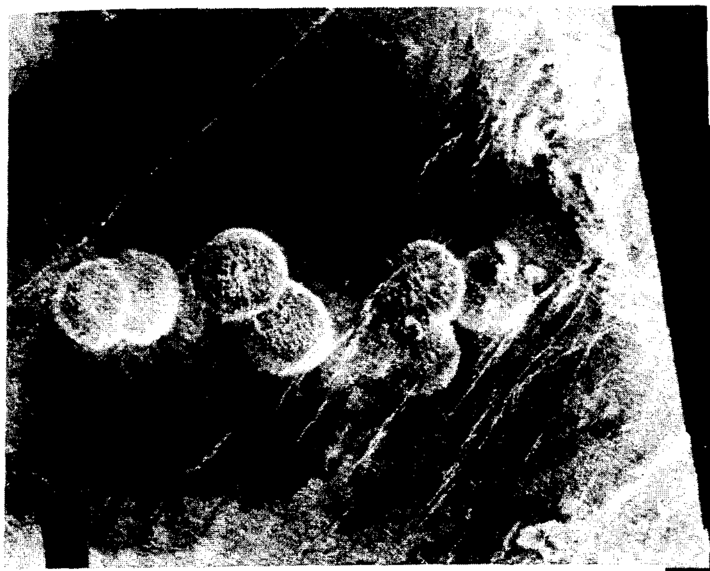
Other studies on possible major space missions the nation might undertake also concluded that these missions must rely heavily upon robotics and automation. Indeed, the missions considered are probably impossible without considerable use of robotics and automation in space. However, the development of new robotics and automation technology has proceeded more slowly than anticipated half a decade ago. The problems that have been encountered are complex and require expensive facilities to address. Progress has been made, and NASA has some very impressive results to show. Nevertheless, the progress has come in smaller steps and more slowly than expected.

In view of the criticality of these technologies to almost all possible future long-term NASA missions, it is important that efforts be continued, perhaps even increased, so that the needed robotic and automation technologies will be available when needed. However, it is realistic to assume that the state-of-the-art of robotics and automation will not be sufficient to replace all EVAs in the Space Station Program. Therefore, EVAs, both planned and contingency, will likely be required. Extensive work still remains to bring the amount of these EVAs down to manageable levels, and to find the maximally effective mix between robotics/automation and EVA.

TETHERED SATELLITE SYSTEM (TSS)
(Ref: Finding #34)

The Tethered Satellite System consists of a fixed base pallet, which includes a 12-meter extendable/retractable boom to launch and dock the satellite at a safe distance from the Orbiter. The system is designed to fly the satellite up to 62 km, either above or below the Orbiter while connected to the boom by a conductive tether having a diameter of 2.5 mm. The first mission will deploy the satellite to 20 km above the Orbiter to verify control, operation, and the retrieval characteristics of the system. Limited scientific investigations in the general areas of tether dynamics, spacecraft environment, and space plasma physics will be conducted.

The satellite is equipped with reaction thrusters to provide in-line, out-of-plane, and yaw control. The in-line thrusters are necessary to provide positive tension on the tether if there should be a situation where the tether slacks. This could happen if the reel should jam, and may result in the loss of satellite attitude stability and a potential impact with the Shuttle or a wrap-around of the Shuttle.



MAGELLAN IMAGE OF VENUS' EASTERN EDGE OF ALPHA REGIO

MAGELLAN'S FULL-RESOLUTION MOSAICKED IMAGE DATA RECORD

HUBBLE PICTURE OF GASEOUS RING AROUND SUPERNOVA 1987A

IV. APPENDICES

A. NASA AEROSPACE SAFETY ADVISORY PANEL

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Aerospace Consultant
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Staff Assistant

B. NASA RESPONSE TO MARCH 1990 ANNUAL REPORT

SUMMARY

In accordance with the Panel's letter of transmittal, NASA's response dated July 18, 1990, covered the "Findings and Recommendations" from the March 1990 Annual Report.

Based on the Panel's review of that response and the information gathered during the 1990 period, the following items noted in the July 18th response are considered "open" at this time. There were 40 findings and recommendations and the following are considered open:

Finding/Recommendation No. and Subject		Comments
#2	Space Station Freedom Program Disruptions	Everyone agrees that "something" must and will be done. The Panel intends to exert its influence as appropriate.
#4	Augmentation of efforts regarding the many areas of life sciences/ human factors	The Panel will reexamine the various activities at NASA and its contractors to assess status and further requirements.
#7	Assured Shuttle Availability Program	The Panel intends to continue to review, assess, and make appropriate recommendations regarding this most important area.
#9	Orbiter vertical tail loads	As noted in this year's report, the Panel will complete its assessment.
#11	Orbiter OV-102 Instrumentation (Loads)	As noted previously, the Panel continues to review this work until there is satisfactory flight results. For example, if the calibration test is conducted only after collection of data, it may not obtain the required transfer functions, then some of the gages will have to be rearranged and the flight tests repeated. Note that the manufacturer's calibration of the strain gages before flight will only show that the gage will respond correctly to the application of loads at various points on the wing. The 263 strain gage channels on the wing should be enough to combine the proper gages mathematically and obtain influence coefficients if calibrated before the collection of flight test data.

Finding/Recommendation No. and Subject		Comments
#16	Solid Rocket Booster aft skirt	The Panel will continue to address this concern as noted in this current annual report.
#18	Solid Rocket Motor case-to-igniter and case-to-nozzle joints	These joints appear to be operating well, but recent evidence indicates that perhaps more attention may be needed regarding "layup" of the putty/sealing material.
#20	External tank waiver for tumble valve (but applies to waivers in general)	As noted in this year's report, the Panel will continue to examine the management of waivers and the like.
#24	Orbiter structural overhaul plans	The Panel will continue to monitor these activities.
All	Space Station Freedom Program	Panel activities will depend upon the disposition of the current reconfiguration and rephrasing activities.
#38	Risk Management and the use of Probabilistic Risk Assessment	The Panel will continue its review of these activities to ascertain possible strategies to use Probabilistic Risk Assessment or similar methodologies to gain more informed management and engineering decisions.

National Aeronautics and
Space Administration

Washington, D.C.
20546

Office of the Administrator

JUL 18 1990

Mr. Norman R. Parmet
Chairman
Aerospace Safety Advisory Panel
9311 Fauntleroy Way
Seattle, WA 98131

Dear ~~Mr. Parmet~~ Norm:

In accordance with your introductory letter to the Aerospace Safety Advisory panel (ASAP) Annual Report dated March 1990, enclosed is NASA's detailed response to Section II, "Findings and Recommendations."

The ASAP's dedication to helping NASA continues to be commendable. Your recommendations have helped to reduce risk in NASA-wide manned and unmanned programs and projects and are greatly appreciated.

We thank ASAP for its valuable contributions and look forward to the next report. As always, ASAP recommendations are highly regarded and receive the full attention of our senior management personnel.

Sincerely,

Richard H. Truly
Administrator

Enclosure

NASA RESPONSE TO MARCH 1990 FINDINGS AND RECOMMENDATIONS

A. OFFICE OF SPACE FLIGHT

MANAGEMENT

Finding #1: Until November 1989, the two principal manned space flight programs--the Space Shuttle and Space Station Freedom--were managed independently, each under the cognizance of a separate Associate Administrator. Since the Challenger accident, Space Shuttle management has exhibited a noteworthy degree of effectiveness and stability. In contrast, Space Station Freedom management has suffered from a lack of continuity in its top-level personnel. Also, the independent status of both programs created some confusion concerning future operational responsibilities. The recent reorganization of the Office of Space Flight places both programs under one Associate Administrator. This change in NASA management is a positive step in seeking stability and cohesiveness in manned space flight activity, especially in flight operations and budgetary planning.

Recommendation #1: NASA, the Administration, and the Congress should support the recent reorganization of the Office of Space Flight and allow that office time to accomplish its objective of achieving a unified and cohesive manned space flight program.

NASA Response: NASA concurs with the finding regarding the recent reorganization and establishment of the Office of Space Flight under a single Associate Administrator. All necessary actions have been taken within Space Station Freedom Program (SSFP) elements to ensure the smooth transition of the organization involved so that the goal of a "unified and cohesive manned space flight program" can be achieved.

Finding #2: In addition to mandated changes in budget and scope, the Space Station Freedom Program has suffered from disruptions in management, especially at the Headquarters level.

While reviewing the work packages at the centers and contractors, the Panel was made aware of the lack or incompleteness of top-level controlling documents, both technical and managerial. The Panel expressed concern about this situation in last year's report. The recent reorganization of the Office of Space Flight offers promise for improving this situation.

Recommendation #2: NASA top management should encourage and provide full support for the new management and structure of the Space Station Freedom Program. Everything possible should be done to ensure technical and managerial continuity of the program.

NASA Response: NASA concurs with the recommendation that "everything possible should be done to ensure technical and managerial continuity of the program." Actions taken by the Office of Space Flight and the Program office in the recent past to bolster the organization and management team were taken specifically to achieve better stability. NASA will continue to strive to provide a viable environment to challenge and retain the leadership and workforce needed to deliver a useful and operational Space Station Freedom.

The problem stated in the finding ("lack or incompleteness of top-level controlling documents") and the related open issue from last years report (item B.1.a) have been extensively worked over the past several months. The result is a comprehensive update of the formal requirements documentation baseline for Space Station Freedom.

FLIGHT READINESS REVIEWS

Finding #3: The return-to-flight of the Space Shuttle has been characterized by extensive preflight reviews. The majority of these, including the roll-out, solid rocket booster/external tank mating, and flight readiness reviews have been conducted face-to-face at the Kennedy Space Center. With the increasing flight rate, the travel and scheduling involved in the multiplicity of meetings are becoming a financial and physical burden. Some of the reviews are being shifted to video or telephone conferences. These techniques conserve travel time and budget, but could reduce the effectiveness of the management review process.

Recommendation #3: The flight readiness, Launch-2 day, and Launch-1 day reviews should continue to be conducted as face-to-face meetings at the Kennedy Space Center. The balance of the prelaunch reviews for each flow may be conducted as either actual meetings or by remote conferencing techniques. This would depend upon interflight schedules and the number/importance of unique problems or issues associated with a particular flight.

NASA Response: NASA concurs with the recommendation. The Flight Readiness Review, and the Launch-2 Day and Launch-1 Day reviews will continue to be conducted as face-to-face reviews at the Kennedy Space Center. For the L-2/L-1 reviews, some JSC support elements (flight directors, weather, etc.) must remain at JSC to support, the terminal count. Therefore, some JSC elements have been supporting, and will continue to support the L-2 and L-1 reviews by telephone. The Level III project reviews, ET/SRB MATE Review, Orbiter OPF Rollout Review, and Launch Site Flow Reviews can be conducted by telephone with proper representation. Detail requirements, formats, and designated face-to-face meetings are contained within the NSTS 7000, Level I, Program Requirements Document, Appendix 8 (NSTS Operations).

TECHNICAL ISSUES

Finding #4: Many of NASA's currently planned activities such as extended duration orbiter, Space Station Freedom assembly operations, extended duration crew operations, and extended duration missions beyond earth orbit may face significant safety problems arising *from inadequate consideration of human performance and human capacity. Potential human performance problems can arise from either extended normal operations that exceed the knowledge base for humans in space or from unexpected (non-nominal), and even unforeseen events (unexpected and not part of the training syllabus), that will certainly occur during long-duration missions.*

Recommendation #4: NASA should embark upon a carefully planned research program to learn more about human performance during extended space operations. Specific attention should be given to the Space Shuttle crew's ability to land an orbiter safely after an extended duration mission. This program might be profitably modeled after the ongoing efforts to examine commercial flight crew workload and vigilance. Much of this work is being conducted at the NASA Ames Research Center and involves full mission simulation and the development of multidimensional measures of workload and reserve capacity.

NASA Response: NASA concurs with this recommendation and believes an augmentation of efforts currently underway will satisfy this recommendation. Under management by the Office of Space Science and Applications, the Life Sciences Division addresses issues of human performance in space, productivity, physiologic reserve, and crew health. A coordinated series of programs are planned to specifically support program development for extended duration orbiter (EDO), Space Station Freedom assembly and operations, and extended duration crew operations, as well as continued operations of the Space Shuttle.

Finding #5: Interruptions in Space Shuttle operations for any reason can have serious consequence to the Space Station Freedom assembly. The Panel, thus far, has seen little evidence of contingency planning by NASA for such eventualities. Contingency planning should extend through all phases of operation. The Panel believes this to be an important area for NASA to emphasize in operational planning.

Recommendation #5: NASA should develop a contingency plan that addresses the issues arising from possible interruptions of Space Shuttle operations during the assembly of Space Station Freedom.

NASA Response: NASA concurs and has actions presently underway. All of the Space Station Freedom stages prior to permanently manned capability (PMC) have an orbital lifetime of at least 1 year and generally closer to 2 years in the normal operating altitude. In the case of a Space Shuttle standdown, NASA could boost any of these stages to higher orbits with orbital lifetime of approximately 2 to 4 years, depending on solar cycle. After PMC, an Assured Crew Return Vehicle (ACRV) will be present; and in the event of a shuttle standdown, the crew could be returned via the ACRV and the station boosted to a higher orbit. These results will be reviewed during the Space Station Program preliminary design review in December.

Finding #6: The goals behind the Space Station Freedom Technical and Management Information System are laudable. It does not appear that this system has been developed in the form or time frame anticipated; nor has there been uniform acceptance of the system.

NASA centers that have been using computerized technical information systems have elected primarily to continue using their own (or their contractor's) system with an intent to convert the data to the Technical Management Information System format when and if the system is able to manage the data.

While a full Technical and Management Information System that is used by all of the Centers and contractors certainly would be an enormous improvement in NASA's operation, it appears that too much was promised and work was started too late with inadequate funding.

Recommendation #6: NASA should rethink the Technical and Management Information System plan and consider a program embodying the following characteristics:

- Whatever system is adopted must be deliverable according to a schedule that matches the need for it among the NASA Centers and contractors.

- Commitment to the system must be firm and the budget maintained regardless of other budgetary pressures.

- Use of the facilities provided must be made mandatory to all NASA Centers and contractors by Level II.

NASA Response: NASA concurs with the recommendations associated with this finding and have taken specific actions and others are in work. The Technical and Management Information Systems (TMIS) Control Board has been reconstituted and is chartered to review and approve information system developments across the program. Applicable Space Shuttle information systems are being adopted to accelerate the availability of needed capabilities and to foster integration with the shuttle program. TMIS has played a crucial role in the rebaselining activities over the past months and will be critical to the SSFP Preliminary Design Review (PDR) and future phases of SSFP operations.

The first phase of TMIS was to implement the Initial Operational Capabilities defined in TMIS functional requirements. In particular, TMIS implemented a network that supports message and file exchange facilities (including hosts distributed at the Centers) that are used extensively by over 2,500 users representing all elements of the program. These facilities support interchange of data between NASA management, contractors, the International Partners, and other users. Workstations supporting word processing, graphics, spreadsheets, scheduling, and project management for individual program participants have been deployed, and common facilities including high-speed printing and image processing capabilities were successfully distributed to all supported levels of the program.

Initial capabilities that supported the Preliminary Requirements Review phase of the program were then augmented by program-wide document management systems. TMIS now supports a Program Automated Library System (PALS), which today holds the baseline requirements documentation for SSFP, along with many working documents.

Collectively, these represent over 175,000 pages of text and graphics in over 1,600 documents. An Automated Requirements Management System (ARMS) maintains a database of linkages and relationships between the 50,000 various program requirements. These systems were critical tools that were used by Level III management at the Centers and by Level II personnel during the rebaseline effort completed in 1989. Additional administrative and management systems were then developed and deployed and are now in active use throughout the system. These include the Program Master Plan/Master Schedule (PMP/MS), Budget Resource and Information Management (BRIMS), Action Tracking System (ATS), and the NASA Automated RID (review) Tracking System (ARTS). An Engineering Data Base has been established, which today contains the critical Assembly Sequence and Resource Allocation (AS/AR) data (weight, power, volume, etc.) that are necessary for completion of the Level II integration responsibilities. All of the above systems are critical tools that are being used to support the PDR process and will be used during the Integrated System Program Design Review. Many also are being used directly during the Level III PDR activities, and some systems such as BRIMS are in constant use by the Centers for support of the NASA Program Operating Plan cycles.

Additional technical support systems, using the Engineering Data Base, are being implemented as required to support SSFP Critical Design Review (CDR) and other future phase requirements. These systems address Technical Planning and Scheduling, Commonality, Supportability, Flight and Orbital Support Equipment, Ground Support Equipment, Engineering Drawing Models, Design Knowledge Capture, Integrated Master Measurement Command List, Master Verification Database, and Integrated Risk Assessment [including Hazards, and Failure Modes and Effects Analysis (FMEA)] requirements. The implementation of these systems will be a major thrust of the Fiscal Year 1991 development efforts.

An Electric, Electronic and Electro-Mechanical (EEE) Parts Information Management System (EPIMS) has also been developed. This system has been designed to control the selection procurement, testing and application of EEE parts to the Space Station Freedom.

TMIS has completed procurement of a Computer Integrated Engineering (CIE) system which, when fully deployed, will become the central repository for design and "as-built" archival engineering data that will be obtained from the work package contractors as work in progress is completed. Such a common repository will complete the variety of CIE systems currently in use today by various elements of SSFP, and will be key to successful design, launch, operations, and on-orbit maintenance of Space Station Freedom. The TMIS CIE will be necessary to the integration of components from the Centers to ensure final fit and finish, since the Space Station will not and cannot be built in its entirety on-ground prior to its deployment on-orbit.

The Administration fully endorses the requirement for continued funding of TMIS at the appropriate level, and intends to deliver additional evolutionary systems and services to SSFP users throughout the life cycle of SSFP through TMIS.

B. SPACE SHUTTLE PROGRAM

ASSURED SHUTTLE AVAILABILITY PROGRAM

Finding #7: NASA management has proposed the Assured Shuttle Availability Program with excellent objectives. The goal of this program is to improve safety and reliability, replace obsolete equipment, achieve and improve flight rate, reduce recurring costs, and improve performance and capability to support NASA objectives. The steps being taken to enhance safety and reliability are of particular interest to the Panel, although it is somewhat difficult to address these two areas separately from the others. Full implementation of such a program would be a step forward in enhancing Space Shuttle safety.

Recommendation #7: The Assured Shuttle Availability Program should be formalized such that scheduled upper management reviews are conducted. Milestones should be established leading to change incorporation on a specific date. A specific budget item for the program should be established.

NASA Response: NASA concurs and action is in work. The Assured Availability Program, which had been proposed in NASA's FY91 budget, was deleted by the Office of Management and Budget. However, NASA continues to consider the primary objectives of the Assured Shuttle Availability (ASA) program to be essential to the successful long-term operation of the Space Shuttle. Actions have been taken by the Space Shuttle Program to preserve the option of implementing several of the more significant items while budget priorities are being reassessed. Proposed ASA changes have been identified and prioritized. The Space Shuttle Program has approved funding for studies and feasibility assessments of the following specific high priority items:

- Redesigned Orbiter Cockpit Displays
- SRB Control System Redesign
- Orbiter Integrated Orbital Maneuvering Subsystem/Reaction Control Subsystem (OMS/RCS)
- SRB Aft Skirt Redesign
- RSRM Igniter Joint Improvement.

These studies are scheduled for completion in late 1990. Implementation decisions and funding requirements will be based on the results of the studies. Similar studies for other important improvements, such as main engine advance fabrication, will be initiated as funding permits.

NASA is preparing rationale for a start of the ASA program in FY92. This funding approach will result in a strongly structured program with clearly defined objectives for implementation, as well as a well-defined management structure to ensure maximizing the gain for the available funding.

SPACE SHUTTLE ELEMENTS

Orbiter

Finding #8: Proposed modifications of certain wing structures to achieve a 1.4 factor of safety over a larger portion of the design flight envelope are being evaluated for cost and schedule effects.

Recommendation #8: The wing structure modifications should be incorporated as soon as possible.

NASA Response: Orbiter wing modifications identified as group 1, 2, and 3 have been accomplished. These modifications were based primarily on the first five Space Shuttle in-flight measured loads, which were higher for certain wing locations than prelaunch predictions (due to a small shift in the aerodynamic distribution caused by engine and SRB plumes). The modifications strengthened the structures in the wing's leading edge, but excluded the wing root (due to inaccessibility). Given the 1.4 factor of safety, the trajectory shape had to be changed to fly within the revised "q-alpha" and "q-beta" boundaries to ensure that an adequate safety margin was maintained. As a result of having to trade performance requirements against launch probability the concept of alternate I-loads (alternate trajectories) was developed to resolve this conflict. This concept has repeatedly provided high launch probabilities for very high performance missions.

Based on the 6.0 loads analysis, final trade-off studies of performance versus cost for the proposed wing modifications were conducted. The studies showed that the modifications would "round" a 45 degree edge of the envelope, which slightly increases the Orbiter flight capability. Based on the small increase in flight capability, it does not appear the wing modifications are warranted at this time. A safety factor of 1.4 or better is always maintained within the present flight envelope. High launch probabilities are obtainable within the present flight envelopes through the use of alternate I-Loads. In the future, higher launch probabilities may be obtainable through the use of day of launch (DOL) I-Loads presently under development.

Finding #9: A recalculation of the loads and stresses in the vertical tail using a revised aeroelastic math model resulted in a more than 20 percent reduction in the airloads on the tail. This enlarges the allowable flight envelope.

Recommendation #9: As the large reduction of airloads on the vertical tail has been obtained by a revised analysis only, the reduction should be confirmed by an independent means such as in-flight strain gage measurements or an independent analysis.

NASA Response: NASA agrees, instrumentation flown on Orbital Flight Test (OFT) is being reconnected to measure structural response in the vertical tail.

NASA has established a Modular Auxiliary Data System (MADS) Aero/Structures Instrumentation project to repair and channelize strain gages and pressure transducers on OV-102 for STS-35 and STS-40. After the instrumentation is repaired and tested to ensure proper operations, airloads on the vertical tail will be obtained. In addition, an independent analysis led by Charlie Blankenship of the Langley Research Center, will be initiated to confirm the vertical tail load reduction.

Finding #10: It is planned to modify the Orbital Maneuvering System pod deck frames during 1991 and 1992 to provide the requisite factor of safety over a broadened flight envelope. Without such modification, an elaborate calculation to verify structural adequacy must be made for each flight.

Recommendation #10: NASA should reexamine its plans for the incorporation of the Orbital Maneuvering System pod deck frame modification with a view towards implementation at an earlier date than currently planned.

NASA Response: Any modification of the OMS pod deck frames (aft fuselage frame caps) will significantly impact Shuttle schedules because such a modification cannot be made for a given Orbiter between successive flights. Consequently, to preserve the current 1990/1991 flight schedule, the modifications for each vehicle will be done during the major modification period for that vehicle. However, modifications that include installation of vent valves on all Orbiters can be done between successive flights without schedule impact. Such changes are currently in progress. Until the major modification is complete, the vehicles will be flown protecting a 1.4 factor of safety using a load indicator calculation that is part of the computer program that evaluates loads based on measured winds. The installation of the valves will reduce the maximum pressure across the pod deck, mitigating the restrictions applied by the 6.0 loads analysis on the flight envelope.

Finding #11: NASA plans to calibrate the OV-102 structural loads instrumentation (pressure and strain gage) well after the collection of flight data instead of immediately before the flight.

Recommendation #11: As the proposed postflight calibration of loads instrumentation would compromise the validity of the data collected, an end-to-end calibration should be performed prior to the data collection flight.

NASA Response: Starting with STS-32 (OV-102), pressure transducers and strain gages have been implemented on both wings, vertical tail, and other structural components of OV-102. Although all of this instrumentation is not completely operational, the Space Shuttle Program has approved and funded a dedicated instrumentation team to make all OV-102 instrumentation operational. This team has been in place since the beginning of the STS-35 KSC flow. The plan calls for this work to be completed during the STS-40 KSC flow. As part of the instrumentation activity, all pressure transducers are end-to-end calibrated prior to flight. The Kulite pressure transducers are calibrated prior to each flight and the Gould pressure transducers are calibrated before and after the first flight of each transducer. These calibrations provide for improved accuracy of Flight data and provide a status of the pressure instrumentation system health. Postflight quick look instrumentation reviews are conducted to identify all nonoperational instrumentation with corrective actions baselined by the Space Shuttle Program's Launch Site Flow Reviews.

The Space Shuttle Program also has approved and implemented strain gage instrumentation on OV-102. A load calibration of the strain gage instrumentation is planned for the OV-102 major modification period that is scheduled for 1991. The strain gage instrumentation system is used to gather data for two purposes. The near-term purpose is to compare measured strain to certified structural capability. The only calibration required for this purpose is the strain gage manufacturer's calibration that applies to the installed gage. These strain gage lot calibrations are stable and have adequate accuracy. The long-term purpose of the strain gage instrumentation system is to define external load distributions. To determine external load distributions requires that strain gage load calibration be conducted to define influence coefficient matrix. This calibration defines the influence coefficient matrix, which converts measured structural response (strain) to applied external loads. The calibration is conducted by applying known loads at a matrix of wing locations and measuring the strain gage output for each load application. This calibration can be conducted either before or after strain data are collected, as long as the strain gage measurement system remains stable. The purpose of the strain gage measurement system is to collect strain gage data from multiple flights. Because there are significant timed and vehicle access requirements associated with conducting the strain gage load calibrations, it is not practical to conduct the load calibration prior to each flight and is only required to be conducted one time. Although an end-to-end strain gage calibration prior to data collection may be desirable, experience with similar equipment and installation indicates that the characteristics of the strain gage system sensors and electronics should remain relatively stable from the time of data measurement until the OV-102 major modification period. The ultimate objective of the OV-102 instrumentation activity is to verify the Space Shuttle ascent aerodynamic pressure distribution that is the basis of the Space Shuttle structural capability. This objective will be accomplished by analyzing strain gage data and pressure transducer data gathered from all OV-102 flights prior to OV-102 major modification using the influence coefficient load calibration.

Finding #12: Review of the data from postflight inspections of orbiter windows indicates that frequency of damage to the windows is greater than previously believed.

Recommendation #12: NASA should consider incorporating thicker or improved glass to enhance the safety margin of the windows as well as implementation of operational techniques such as pre-selecting on-orbit attitudes and entry angle of attack to minimize exposure to debris or thermal effects.

NASA Response: Review of postflight inspections of orbiter window shows that frequency of damage to windows is well within values predicted by Rockwell at the beginning of the program. Thicker windows have been considered in the past as an improvement that would reduce turnaround time for the orbiter. Though improved glass will undoubtedly improve the thermal pane's ability to withstand impacts by reducing the stress on the pane's surface, there always will be a hypervelocity particle that can penetrate the pane. A redundant thermal pane window design may be feasible to incorporate within the vehicle to provide another layer of protection against the risk associated with a failed thermal pane.

Vehicle on-orbit operational attitudes that could minimize exposure to debris have been reviewed, though more work needs to be done. Uncertainties in the analysis data presented to date are greater than the risk reduction a different attitude would give. The probability of a particle large enough to penetrate the thermal pane is very small, about 10 to the minus 4 for a 7-day mission. Thus, the risk is small for continuing to operate without attitude restrictions. The effect on the vehicle during entry for the crack and/or loss of a thermal pane is being studied. Entry profiles that could be flown to minimize thermal stresses on a cracked window and surrounding structure will be evaluated once the damaged window study has been completed. Current mission rules require an orbiter entry at a cabin pressure of 10.2 psi for the loss of a thermal pane, thereby minimizing stresses on the remaining panes and window structure.

Finding #13: *During preparations for the launch of STS-29, an incorrect set of software for the ascent phase was produced and sent to the Kennedy Space Center. The error was caught by a comparison with an independently created "build" from Rockwell and IBM. The error was easily corrected once found.*

Recommendation #13: The incident emphasizes the need for an independent verification and validation system for software testing. Such a system should have the following attributes:

- Independent validation of the software generation procedures employed
- Independent check of the tests employed to verify the software generated
- Thorough validation of the software generation and check procedures from a safety point of view
- Traceability provisions
- Software failure modes and effects analysis.

NASA Response: NASA is meeting the intent of the recommendation for an independent verification and validation for software testing. The system did allow a software error in the software build to be sent to the KSC. The late parallel independent software check between Rockwell and IBM, that allowed this error to be sent to KSC, has been corrected. Key factors of the STS-29 Flight Software (FSW) incident are briefly described as follows:

- The STSOC FSW reconfiguration contractor omitted two SSME software patches from the STS-29 complementary FSW load delivered to KSC. This error pointed out a process problem in the STSOC complementary load build process particularly, as well as a process in the basic FSW reconfiguration process for Recon 1 and Final Load.

- IBM, the primary FSW development contractor, also performs what we call "Parallel Certification" of all mission integrated mass memory FSW reconfigured and produced by STSOC (RI-Downey, the backup FSW development contractor, also performs Parallel Certification of the mission backup FSW reconfigured by STSOC). IBM, in their Parallel Certification role, caught STSOC's omission of the SSME patches by comparison of STSOC's integrated mass memory with that independently built by IBM.

- The SASCB Chairman, per standard procedures, approved the Release Authorization Sheet (RAS) authorizing use of the STSOC complementary load in the field (KSC, SAIL, etc.). IBM Parallel Certification comparison results were not required to be completed before RAS authorization. Therefore, the RAS authorizing use of the STSOC complementary load was executed before knowledge of the Parallel Certification miscomparison.

A thorough review of the STSOC FSW reconfiguration process was conducted and all recommended process changes have been implemented. The Parallel Certification activity is still firmly involved in the FSW mission certification process. But ever since this STS-29 complementary load incident, RAS's require Parallel Certification statement regarding results of the bit-for-bit comparisons; therefore, no FSW product will be released to the field without confirmation from Parallel Certification with proper bit-for-bit comparisons.

Relative to ASAP's recommendation, the Space Shuttle Program totally concurs that the "Parallel Certification" activity performed by the FSW development contractors is required and plays a significant role in NASA's independent verification and validation (IV&V) system for software testing. This Parallel Certification/IV&V activity provides independent validation tests since Parallel Certification has developed their own FSW build procedures, builds their own integrated mass memory, and defines/conducts their own verification tests. Both STSOC and Parallel Certification have well documented audit/traceability systems in place. The JSC SR&QA provides an oversight of the FSW process--they are represented on the Shuttle Avionics Software Control Board (SASCB) and have their contractor (Ford Aerospace) perform independent requirement-to-code audits of the FSW. There is no classic FSW failure modes and effects analysis (FMEA), and both JSC-SR&QA and the Space Shuttle Program do not view this as necessary. Formal FSW analysis and discrepancy resolution is performed on all FSW. These analyses include test runs on multiple test facilities, e.g., SAIL, SMS, and SPF, as well as off-line processors and constitute a thorough assessment of the FSW.

In summary, the present FSW Parallel Certification process and SR&QA provide the program with all the necessary IV&V attributes recommended by ASAP. The program concurs with ASAP that this Parallel Certification IV&V activity is a significant element of the FSW process and must be continued. However, the FSW verification and testing eliminates any need for a FMEA.

__Finding #14:__ NASA faces a significant problem with respect to its Space Shuttle computers that has not been addressed: a third generation of computers to replace the new computers to be installed in 1991. While it may seem premature to consider a third generation computer before the second generation has been installed, the rate at which computer technology is advancing compels such a consideration. Additionally, in the near future, NASA will have two major flight computer systems to manage (those of the Space Shuttle and Space Station). Both will be obsolete before the orbital assembly of the Space Station commences.

__Recommendation #14:__ NASA should begin planning now for a process of regular upgrades to the Space Shuttle and the Space Station Freedom computers including, perhaps, a transition to the use of a common underlying computer architecture for the two systems.

__NASA Response:__ NASA concurs with this recommendation for the long term but disagrees that this is a near-term issue. NASA believes that efforts currently underway are sufficient to identify and provide any necessary upgrades to the Space Shuttle and Space Station Freedom computing systems.

The new Space Shuttle General Purpose Computer (GPC) is scheduled for its first flight on STS-41 in October 1990. Design work for the new GPC began in January 1984, and the first new computers will be flown in late 1990 or early 1991. The calendar time required to design, test, and certify such a man-rated system practically assures that system to be technologically obsolete for most of its operational life. The expected life of the new GPCs is 15 years. Subsequent major changes to the computer system architecture would require revision of the complete avionics package. NASA believes that any consideration of possible further improvements to the GPCs or to the computer system should be an integral part of the Assured Shuttle Availability (ASA) Program.

The Space Station Freedom Program (SSFP) is planning for the upgrading of computers and/or software as improved technology permits. This planning, documented in its highest level program document, the Program Requirements Document (PRD), and in its second level requirements document, the Program Definition and Requirements Document (PDRD), is in two areas. First, the SSFP is planning for mainframe computer hardware and support software replacement every 7 years and workstation replacement every 5 years during the program's operational phase. Second, the program is establishing evolutionary requirements allowing the flexibility to upgrade to advance technology as it becomes available. As a result, requirements for the operational Space Station Information System require a design that isolates applications software (both flight and ground) from the underlying computing system. This promotes the migration of ground hardware and software to the flight systems or from facility to facility, and maximizes flexibility for replacement of flight hardware during the life of the program.

Transition to the use of a common computer architecture in both the Space Shuttle and Space Station is not considered feasible due to the differences in the underlying design philosophy of the two systems. The Space Shuttle, although relying on five computers (four primary and one backup), is essentially a centralized system fully integrated with the avionics package. Migrating the Space Shuttle computer architecture to some other design, such as that employed by the Space Station, would require the complete redesign of the avionics system. The Space Station, on the other hand, employs a decentralized system utilizing microcomputing technology as its driving force. Additionally, these systems employ radically different operating systems, programming languages, and are subject to different weight and volume constraints.

Space Shuttle Main Engine

Finding #15: The Space Shuttle Main Engines have continued to perform satisfactorily in flight. Operations are hindered, however, by the need to replace the high pressure oxidizer turbopump bearings after each flight. The impact of this requirement is mitigated by an increase in the number of spare turbopumps available. The flight bearing wear detection instrumentation that is being developed holds promise of permitting safe reuse of "healthy" bearings in the near term. Modifications of the bearing installation now in test have the potential for alleviating the high pressure oxidizer turbopump bearing wear problem.

The development of the two-duct power head (hot gas manifold) has continued with test results as good as, or better, than predicted. Incorporation of this change will alleviate some of the loads internal to the engine; specifically, those resulting from non-uniform velocity and pressure distributions in the flow passages caused by the present three-duct power head. Certification of the two-duct design is planned.

Work on the large-throat main combustion chamber has progressed slowly. Test data show that it provides major reductions in turbomachinery stress levels and environments. Combustion has been demonstrated to be stable and systems effects that would accompany its incorporation can be accommodated by straightforward modifications to other components; some of which are in work for other reasons. The large-throat main combustion chamber still is not a part of the engine improvement program even though it offers major increases in operating safety margins. The activity is treated as a technology program. Current opinion maintains that if the chamber is to be included in the engine improvement program, it should await other changes and be incorporated as part of a "block change" to the engine.

The alternate turbopump development program is nearing the major component test phase. The design is intended to incorporate the lessons learned from the development and operation of the current turbomachinery. The program also benefits from the ability to test individual turbopumps in a component test facility rather than on an all-up engine.

Recommendation #15: Since all of the engine modifications being developed enhance the safety margins of the system, these developments should be worked as expeditiously as possible. A much more aggressive development program should be instituted. This applies not only to the high pressure oxidizer turbopump bearing modification and the two-duct hot gas manifold, but also to the large-throat main combustion chamber. The latter modification should be made a formal part of the Space Shuttle Main Engine safety enhancement program; a segment of the Assured Shuttle Availability Program and its development and certification should not be constrained by other possible engine improvements. The pace of work on existing turbomachinery should not be decreased based on the anticipation of its replacement by alternate turbopumps, which are still in the early development stages.

NASA Response: A program plan has been developed by the SSME project in conjunction with the contractor and government technical experts, which addresses the identified limitations of the current engines and is structured to aggressively pursue enhancements for improving the engine. A formal program has been defined that includes enhancements to all items identified in the finding/recommendation; and in addition, addresses other concerns such as uninspectable welds in the current design.

In regard to the existing turbomachinery, health monitoring instrumentation modification to address the condition of oxidizer turbopump bearings after flight has been certified and incorporated on the flight pumps, which will permit two flights without removal, provided the bearing signatures are within acceptable limits. The modification was successfully flown on STS-31. The flight certification program to extend the Rocketdyne fuel and oxidizer turbopumps to at least five flights is being aggressively pursued and projected to be completed in 1991.

The near-term engine enhancement plan (FY94 fleet implementation) includes incorporating the phase II+ powerhead, which significantly reduces the severe hot gas flow environment, eliminates the preburner injector pins, incorporates the single tube internal heat exchanger (no interpropellant welds), and other design improvements, i.e., relocates a number of welds for producibility and inspectability. The other FY94 initiative is the implementation of the P&W alternate turbopumps, which significantly reduces the number of critical welds in each turbopump.

The long-range initiative, being pursued as a part of Assured Shuttle Availability (ASA), addresses other major concerns such as uninspectable welds in the MCC, nozzle, powerhead, and ducts, and takes advantage of advance fabrication techniques that will increase safety margins and significantly reduce manufacturing cost. The large throat MCC configuration with the main injector baffle and acoustic cavity elimination has completed characterization testing and appears to offer significant benefits in regard to reduction of the turbomachinery operating environments. The large throat MCC also will be implemented as a part of ASA. Although the large throat MCC and advanced fabrication are not constrained to be implemented together, that does appear to be the most favorable approach at this time.

The ground test hot fire exposure plan is extremely aggressive, and the proposed dates of incorporation into the fleet are largely limited by adequate ground test exposure. The plan is designed to upgrade via block change in 1994, and again in approximately 1996 and would result in an engine in the mid 90's, which positively addresses all known concerns.

Redesigned Solid Rocket Motor and Solid Rocket Booster

Finding #16: *Static structural tests of the solid rocket booster aft skirt demonstrated that a weld cracked at a load equivalent to a 1.28 factor of safety on limit load. The aft skirt was able, however, to support a load equivalent to a 1.41 factor of safety without further failure. Waivers permitting the use of the aft skirt with a 1.28 factor of safety have been processed for each flight.*

Recommendation #16: Despite the successful use of the current aft skirt, it would be advisable to improve the aft skirt in structural design and/or material so that it would demonstrate a 1.4 factor of safety. At a minimum, the analysis of the skirt structure should be improved to permit better comprehension of the load redistribution process after weld failure as well as the effects of the shock produced by weld failure on other booster systems attached to the skirt.

NASA Response: A number of inspection, testing, and analysis efforts are being performed to ensure that the existing aft skirt has adequate design margin and high reliability under all conditions. These efforts include both the normal activities associated with refurbishment and recertification as well as special testing programs to monitor aft skirt weld strains and applied loads during launch, and to develop methods and procedures for increasing the weld factor of safety.

Thus far. the results of the special testing efforts have been very positive, indicating that the aft skirt launch loads and weld stresses were below maximum design values, and that the weld factor of safety can be increased by using a skirt radial preload and careful booster stacking. In addition, a comparison of load-strain relationships from the launches with those from the structural tests suggests that the weld strains do not reach design limit. Therefore, the effective factor of safety for launch is 1.28 or greater. In addition to conducting special test programs, NASA has continued to study and refine the finite element structural models for the aft skirt and the Mobile Launch Platform (MLP) to better understand and model launch results and structural test results. Changes to the aft skirt and MLP models to incorporate moment transfers across the spherical bearing interfaces are in work to explain differences between launch and structural test load-strain results. Moment transfers at the support bearing interfaces (due to friction) may act to reduce weld strain and increase factor of safety. Test results indicate that a radial inward bias of the spherical bearings has the potential for reducing the critical weld stress on the aft skirt provided that bearing sleeve rotation can be controlled.

In addition, NASA is studying a potential new design of the aft skirt with "Assured Shuttle Availability" (ASA) funds, in the event that ASRM drives aft skirt loads above current requirements. The results of this design study, along with loads derived from the ASRM program, will be considered in determining the advantages of implementing a new aft skirt. In any event, the knowledge of the loads on the aft skirt are well understood, and the 1.28 factor of safety is adequate to ensure a safe flight.

__Finding #17:__ The new field joint with capture feature and the "J" seal incorporated in the case insulation have demonstrated in test and flight that they prevent hot gases from reaching the primary O-ring of the joint. The joint heaters are subject to malfunction and the associated protection system can be a source of debris.

__Recommendation #17:__ NASA should continue its search for an O-ring material with improved low temperature elasticity. Such a material would enable elimination of the joint heaters as well as a simplification of the joint protection system and its installation.

__NASA Response:__ NASA concurs that the search for an O-ring material with improved low temperature resiliency should be continued, and is maintaining cognizance of new materials and process developments. However, recent material searches have resulted in no currently available materials, which constitute an improvement over the material now being used. Fluorocarbon STW 4-3339 is the O-ring material that has been selected after extensive testing of numerous material candidates. This material is an improved version (by omission of a filler material) of the Viton 747 Fluorocarbon that was used in the SRM/HPM.

Fluorocarbon STW 4-3339 has the following favorable characteristics: it is compatible with the HD-2 corrosion preventative grease environment in which it must operate, does not significantly absorb nitrogen gas, has acceptable squeeze and resilience properties, functions well in high temperature environments, has good surface hardness for assembly requirements, has consistent and acceptable general materials properties, and has good spliceability. Other candidate materials are significantly deficient by comparison. The silicones nick easily, are not sufficiently rigid, and are hard to assemble. The polysulfones react with lubricants and swell. They can be coated with a barrier layer, but this introduces coating problems, potential delamination, and another failure mode.

The joint heater system is working well with the baseline O-rings, and NASA plans to continue flying this configuration unless a new O-ring material becomes available.

__Finding #18:__ The case-to-igniter and case-to-nozzle joints continue to require extreme care in assembly and installation to ensure a leak-free joint. There is still concern about control and reproducibility in the installation of the igniter joint putty and case/nozzle polysulfide sealant materials. New designs exist for these joints which provide joint closure upon case pressurization and eliminate the need for igniter joint heaters and case/nozzle radial bolts. Such designs have been proposed for the advanced solid rocket motors.

__Recommendation #18:__ NASA should undertake a program to develop and implement the new case-to-nozzle and igniter-to-case joints. This will improve the safety of the redesigned solid rocket motor and simplify its assembly.

__NASA Response:__ Regarding the igniter joint, assembly technique improvements have been incorporated that will reduce the potential for getting putty on the elastomer seals of the gask-o-seal. In addition, higher preloads have been incorporated for the attaching bolts to reduce the gapping at both joints. These modifications are now in place and they should alleviate some of the present concerns regarding the igniter joints until redesigned igniters become available. The igniter joints are in the process of being redesigned per recommendation #18. The goals of the redesign are to make the joints less sensitive to manufacturing and assembly errors, to ensure the joints remain closed so there is no gapping at the seal at limit load, and to improve the insulation system. To accomplish these goals, the redesign will use a thicker adapter plat and longer bolts, and the gask-o-seals will be replaced with O-rings. These changes also will allow for the deletion of the heater. The putty will be replaced by a J-leg type pressure actuated insulation system. Preliminary estimates indicate this redesign can be manufactured, tested, and certified for flight in approximately 1 year.

A redesign of the case-to-nozzle joint, however, is judged to be a substantially more complex and time consuming task than the igniter joint. It is expected that such a major change to the RSRM could not be accomplished much in advance of the planned availability of the ASRM. The preload in the axial and redial bolts is being increased starting with the 14th flight set (STS-41) to enhance the sealing capability of the secondary O-ring. There has been no indication of anomalous conditions with this joint for the first 10 flights.

Advanced Solid Rocket Motor

Finding #19: A major premise in the advanced solid rocket motor program is the automation of the solid rocket motor case insulation process, and of continuous propellant mixing and casting processes. These automated process systems and software do not exist in the forms planned for use. One of the major impediments to successfully achieving such levels of automation has been the difficulty and cost of adapting automation from one application to another. It is not clear from the information provided whether adequate time, research, and budget had been included in the program to develop the level of automation planned.

Recommendation #19: NASA should conduct a thorough review of the plans for automation in the advanced solid rocket motor program. Particular attention should be given to: (1) the level of technical advancement required to achieve the degree of automation specified, and (2) the cost and time required to achieve the automation specified. This should be done by comparison with costs and schedule other industries have experienced when making similar advances.

NASA Response: NASA has reviewed the planned facilities and equipment for the automation in the ASRM program and plans to continue to thoroughly review those plans, with emphasis on the level of technical advancement, cost, and time required to achieve the degree of automation specified. High-level management visibility on automation has been established to assure proper planning and visibility into achieving the degree of automation specified. NASA concurs that care must be taken to ensure that the planned level of automation can be achieved on a realistic schedule within budget constraints. A review panel has assessed the automation of the ASRM in terms of industry experience, cost, and schedule. It is anticipated that this type of assessment will continue as deemed necessary throughout the program.

External Tank

Finding #20: The desire to eliminate the tumble valve has resulted in carrying a waiver for each flight since STS-27. The tumble valve has been disengaged for a number of flights and this has not resulted in External Tank debris footprints outside acceptable limits.

Recommendation #20: The program should either remove the tumble valves in their entirety and eliminate the specification requirement or conduct a process by which waivers are no longer needed for each flight.

NASA Response: In all flights where the tumble valve has been activated, the reentry footprint has remained typical of a tumbling tank and outside the geographical limits of 25 nautical miles from United States landmass and 200 nautical miles from foreign land masses. Mission specific analyses are performed to assure that predicted ET reentry footprints are satisfactory and to establish any risk associated with contingency aborts. The tumble valve will be disabled for missions where the footprint is such that the tumble valve is not required. NASA and DoD Range Safety agree the footprint uncertainties pose no risk to adjacent landmarks. When generic certification of ET entries without an active tumble valve is complete, the tumble valve system will be removed. This generic certification is planned to be completed by the end of FY91 and would enable NASA to eliminate this critical flight hardware from the External Tank.

Launch, Landing, Mission Operations

Finding #21: There is clear evidence that many of the problems that hampered launch processing prior to the Challenger accident are being addressed such as excessive overtime, lack of clarity in work instructions, shortage of spare parts, and heavy paperwork burden. However, these pre-Challenger problems have not been totally eliminated.

Recommendation #21: NASA and the Shuttle Processing Contractor must work diligently to eliminate deviations and errors that still occur frequently in the processing activities. Communications between the Shuttle Processing Contractor middle management and hands-on technicians must be continually improved.

NASA Response: NASA and the Shuttle Processing Contractor (SPC) realize that to safely process vehicles in support of the planned flight rate, occurrences of worker error must be further reduced. To decrease the likelihood of worker fatigue contributing to processing mistakes, the KSC continues to strictly adhere to the overtime policy outlined in Kennedy Management Instruction (KMI) 1700.2. Over the past year, less than 1 percent overtime exceeded the 60 hour/week criteria outlined in the KMI.

In May 1989, NASA/SPC formed a joint Processing Enhancement Team (PET) to reevaluate overall processing procedures. Efforts have focused on three major areas. First, the PET is working to assure that the work task preparation is complete, i.e., all documentation, people, and parts are available when required. Second, the team is working to guarantee that the right people and equipment are available to resolve processing problems as they occur. And third, the PET has found that to enhance processing, standardization is required of planning and scheduling procedures. These representative steps are aimed at clarifying instructions that each worker must abide by in safely completing his task.

Availability of spare parts has improved markedly since return-to-flight. The Line Replacement Unit (LRU) fill rate is roughly 89 percent compared to an average of 80 percent prior to STS-51L. The transition of logistics management responsibility to KSC has greatly improved the support posture. Steps also have been taken in this area by placing commonly used items in the OPF to assure availability to workers. Reduction in the amount of technician downtime has resulted.

The Shuttle Processing and Data Management System II (SPDMS II) is the descriptive title for a computer hardware, software, documentation, and processing system that will provide technical and management information support to shuttle ground processing activities. The project will significantly improve the work control system at KSC by providing faster, more accurate work scheduling, tracking, and approval to support the projected flight rate. Initial phases of this project are now being implemented, with continued incorporation planned over the next 2 years.

NASA/SPC believes the steps summarized above will mitigate the potential for processing errors. A system has been set up by the PET whereby workers can communicate their concerns and ideas about the specific processing tasks to appropriate directorate representatives. Managers continue to emphasize that safety will not be compromised to meet launch schedules. NASA/SPC remains committed to continue improving workmanship and strengthening communication channels between managers and hands-on technicians.

LOGISTICS AND SUPPORT

Finding #22: Continuing review of the overall orbiter logistics and support systems shows that the attention being given by NASA to the development of orderly management and control systems is yielding noticeable improvements. An excellent team spirit has evolved at the Kennedy Space Center among all the contractors and NASA. The virtual completion of the transfer of the Rockwell management and technical group to the Kennedy Space Center area enhances liaison with the Shuttle Processing Contractor (Lockheed) and the Kennedy Space Center logistics authorities. Development of physical stocking facilities and computerized control systems at the Kennedy Space Center is impressive.

Recommendation #22: Keep up the good work and maintain management attention to ensure continuing or better level of work.

NASA Response: KSC is continuing to improve the logistics support for the Space Shuttle program. Program requirements are presented to the top management levels in the program. Cannibalization rates have been reduced to near zero, and the POS rate is above 90 percent. The logistics budget has been supported by management, therefore, NASA expects logistics support to be maintained at the current levels.

__Finding #23:__ The Space Shuttle Main Engine spare availability is marginal as evidenced by the paucity of high pressure turbomachinery. This has lead to complex juggling of main engines to meet operational requirements.

__Recommendation #23:__ Incorporation of Space Shuttle Main Engine reliability and life enhancements should be accelerated to reduce the pressure for spares availability.

__NASA Response:__ The high pressure pumps with extended life capability are in testing and should be available for fleet implementation in FY91. The P&W pumps have just started developmental testing, and are planned for fleet implementation in FY94.

A block change is in the planning stages to minimize welds and use advanced fabrication techniques that will make a safer, more producible, engine. This will reduce the need for spares in the future.

Accelerating these schedules is not considered feasible in that the testing program is the critical element, and it is very difficult to speed up the testing significantly.

__Finding #24:__ The current documentation does not provide a proper plan for scheduled structural overhaul for the orbiter fleet.

__Recommendation #24:__ Provide a structural overhaul plan for the orbiter fleet, which should draw upon pertinent portions of plans of the Air Transport Association for aging commercial aircraft.

__NASA Response:__ NASA, with the assistance of Pan American Airlines, has developed a set of structural inspection requirements for the Orbiter vehicles. The requirements are documented in the Orbiter Maintenance Requirements and Specifications Document (OMRSD), NSTS 08178, File III, Vol 30. These identify the areas to be inspected, the inspection technique, and the inspection interval. Inspection intervals are based on the type of structure involved, the nature of degrading influences (e.g., fatigue, corrosion, temperature), and the results of previous inspections. These inspections are grouped into intervals of every flight, every five flights, every nine flights, etc. All vehicles were inspected during the post STS 51-L down period. In addition, the flight manifest includes provisions for major structural inspection periods to include those areas not accessible during normal turnaround operations. The next will occur on OV-102 (Columbia) in the summer of 1991.

__Finding #25:__ While the logistics management responsibility transfer has worked well for the Space Shuttle orbiter, little or no progress has been made in the transfer of responsibility for propulsion (MSFC elements) and orbiter GFE spare hardware necessary for the assembly of these elements into a complete system. These pieces are mostly small hardware items such as bolts, nuts, covers, and lubricants.

__Recommendation #25:__ All of the spare parts needed to mate the Space Shuttle elements at the Kennedy Space Center should become the responsibility of the Kennedy Space Center logistics function.

NASA Response: NASA's current Level I policy (NSTS 7000, Appendix 12) was updated in July 1989 after a complete program review. The policy directs that management responsibility for logistics support of the flight elements systems and their GSE be transitioned from the flight element project office to KSC, "without impacting the Space Shuttle Program safety, reliability, or launch schedules." KSC will negotiate a Logistics Management Responsibility Transfer (LMRT) agreement with each flight element project office. It is the Space Shuttle Program's intent to transfer those items that make sense from both the hardware project and KSC's vantage point. It does not necessarily mean that all of the spare parts needed to mate the Shuttle elements will be transferred. This is an area that will be reviewed on a continuous basis to insure that items are transferred when appropriate.

C. SPACE STATION FREEDOM PROGRAM

PROGRAM CONTENT

__Finding #26:__ The reduced funding in the FY 1990 budget has required NASA to reexamine the content of the technical baseline of the Space Station Freedom Program and make decisions as to what should be retained or postponed for later consideration. A new management team and a reorganization of the program office, particularly the systems engineering and integration activity, should allow for the unimpeded conduct of preliminary design work leading to the preliminary design review scheduled for December 1990.

__Recommendation #26:__ There are no specific recommendations other than to give appropriate attention during the coming year to those changes and deferrals having the most impact on system safety and reliability.

__NASA Response:__ NASA concurs with the concept that safety and reliability must be recertified after any technical or design change. The SSFP has been rephased without compromising safety and reliability. The program is committed to resolve any safety or reliability issues that are identified, and it will be a specific focus on the upcoming PDR. In addition, specific studies have been commissioned to review various technical areas, and as the findings mature, actions will be taken to resolve all safety and reliability issues.

TECHNICAL ISSUES

__Finding #27:__ Space environmental factors, including orbital debris and radiation, are critical to the design of the hardware and basic station configuration as well as operations during and after assembly. No previous manned space vehicle has been subject to such environmental factors over extended periods of time.

__Recommendation #27:__ Since much attention continues to be given to orbital debris and radiation issues (accentuated by the return of the Long-Duration Exposure Facility), early decisions should be made regarding design and operating requirements to support hardware design and required test program.

__NASA Response:__ NASA concurs and has actions underway. NASA agrees that the Space Station Freedom will be exposed to the space environment for a longer period of time than any previous manned spacecraft. NASA recognizes that the Long-Duration Exposure Facility (LDEF) provides a unique opportunity to examine long-duration, synergistic space exposure effects; and to enhance understanding of space environments definition, effects, and mechanisms. As a consequence, an LDEF Data Analysis Project Office has been established. The work of the Project is carried out by special investigative teams and LDEF Principal Investigators. Special investigative teams have been formed on micrometeoroids and orbital debris, radiation, materials and systems. The teams have placed highest priority on:

- Those analysis most relevant to spacecraft design and operations issues
- Understanding the context of LDEF findings with regard to changing environments during various phases of the LDEF mission
- Performing appropriate extrapolations for usage in other contexts, e.g., Space Station Freedom

Team members have been drawn from experts in the four discipline areas and represent multiple institutions and programs within NASA and DoD. These teams are structured to provide the desired "peer review" for evaluation of the implications of LDEF analyses. The LDEF analyses are examined within the context of other ground-based and flight data analyses to verify and improve ground-based simulations, testing and modeling. The LDEF analyses is also used to investigate accelerated testing methodologies. SSF representatives on each of these teams play a vital role in planning, implementing, integrating, and utilizing LDEF analyses to serve immediate and long-term SSF interests. Incorporation of LDEF information into the design and operating requirements of Space Station is an ongoing process. There is superb recognition within the LDEF investigator community of the urgent need for their analyses. This has resulted in unprecedented levels of cooperation and informal communication of LDEF results. The first major LDEF data workshop will be held in October 1990.

Finding #28: Ingress/egress to and from the Space Station Freedom poses several issues: Space Shuttle docking, extravehicular activity airlocks, and intermodule movement; each of which has safety ramifications. The current design has two Space Shuttle docking hatches; however, it is not possible for two Space Shuttles to be docked simultaneously because the docking ports are too close together. A failure that prevents separation of the orbiter and station could result in an emergency situation. Since the second airlock has been removed, this creates a critical single-failure-point and may elevate the criticality of other areas in that the crew will possibly have to move through a very difficult path to reach the single airlock in the event of an emergency.

Recommendation #28: Because of the criticality of the airlocks, the Panel believes that the reduction to a single airlock is an unacceptable risk. NASA should reconsider the decision to eliminate the second airlock and add it back into the configuration. NASA also should reexamine the entire issue of crew egress under a wide range of credible component and operational failures.

NASA Response: The current design requirements are being met with the single airlock. These requirements will be reviewed carefully, both in the multiple Level III PDR's and in the Integrated System PDR, which will occur in December 1990. Should the more detailed assessments reveal that a second airlock is required, then it will be incorporated into the baseline prior to the commencement of detailed design. Assessment of several emergency situations is also a part of the PDR process and the Design Reference

Missions (DRM), as well as the traditional Failure Modes and Effects Analyses (FMEA) and hazard analysis. In all of these assessments, crew egress will be evaluated as to its adequacy for evacuating any dangerous area of the Space Station Freedom.

*Finding #29: Safety of the internal environment deals with toxic and hazardous spills, fire, and depressurization/repressurization. Although many precautions are to be employed during the handling and storage of toxic or hazardous materials (which should prevent most spills or atmospheric contamination), it is not enough to assume **no** spills will occur. For a planned 30-year life, fire safety is a critical aspect of design. Protecting and maintaining a safe internal environment in the station currently includes the ability to repressurize the modules one time after a deliberate depressurization.*

Recommendation #29: Even though provisions are being made to handle spills, fire and depressurization, specificity is necessary in the requirements to accomplish hardware design and proper integration with other safety-critical functions and systems. A better understanding of fire initiation, propagation and extinguishment in a zero-g environment is required. Therefore, NASA should assure that a coordinated program is available to support fire safety activities.

NASA Response: NASA concurs and has actions underway and planned. Regarding hazardous spills, an ad hoc working group has begun definition of appropriate spill kits to manage spills should they occur. Preliminary definition suggests that a modest number of such kits will control the identified hazardous material on the station. NASA recognizes that fire initiation, propagation, and suppression is different aloft than in the terrestrial setting. It also is acknowledged that specific combustion experiments in weightlessness would yield useful data relative to the fire detection and suppression on the Space Station Freedom. The present preliminary design for fire detection and suppression will be reviewed at the Integrated System PDR in December 1990

Depending on the outcome of this review, specific studies will be undertaken to verify that the current design will accomplish fire detection and suppression as the designers originally envisioned. These studies would likely commence as early as the summer of 1991, and would logically include whatever combustion experiments were thought necessary to be performed in weightlessness.

Finding #30: The Space Station Freedom is supposed to have common berthing mechanisms throughout. Currently, the design calls for 24 active-rigid, 12 passive-rigid, and 6 passive-flexible mechanisms. These are essential to station assembly and operations, including those with NASA's international partners.

Recommendation #30: Multiple interfaces among these berthing mechanisms require close attention by the work package organizations (NASA and contractor), systems engineering and integration organizations as well as with the international partners. Thoroughly defined specifications and drawing requirements must be provided and maintained to assure compatibility.

<u>NASA Response</u>: NASA concurs and a common berthing mechanism will be used throughout Space Station Freedom. The Work Package 1 prime contractor, Boeing Aerospace Company, is responsible for design and certification of all berthing mechanisms employed on Space Station Freedom.

<u>Finding #31</u>: Extravehicular activities are heavily involved in Space Station Freedom assembly and operation, maintenance/repair, and emergency actions; and with the flight telerobotic system. The decision has been made to use the current Space Shuttle space suit for the foreseeable future.

<u>Recommendation #31</u>: Because of the limitation of the current space suit, operational timeliness and support training require close coordination between the JSC Flight Crew Operations Directorate and all the work package organizations. Particular emphasis should be placed on the work of the Space Station Freedom assembly sequence planning groups and their interaction with the human factors people and crew training curriculum.

<u>NASA Response</u>: NASA concurs and actions are underway. NASA acknowledges that the successful completion of the assembly process is challenging. It is recognized that the most effective and efficient use of orbiter-based Extravehicular Activity (EVA) necessarily involves close cooperation with the crew in terms of planning, training, human factors, and performance considerations. A specific group, the Assembly Planning Review, has been established at the Johnson Space Center to consider the details of the assembly process with an emphasis on operational issues. The group is chaired by an astronaut, Capt. David Walker. This group was established in 1988, and has functioned well in terms of incorporating crew considerations into the design process. NASA is expending a significant effort into task analysis for the robotics for Space Station Freedom, particularly the Canadian remote manipulator system.

<u>Finding #32</u>: In the safety and product assurance area, the Level II, III and IV organizations have begun to achieve a more coordinated and effective working relationship during this past year. They now work directly with the Space Station Freedom Program office as team members in performing their engineering and systems safety work. They also provide independent assessments to assure that safety and product assurance are being given proper consideration.

<u>Recommendation #32</u>: Maintain and enhance the current collaborative relationship between safety and product assurance organizations and the program/element offices. There is a need to formalize the various safety and product assurance documents as soon as possible to assure that such requirements and methodologies are in place and will support the activities leading to the preliminary design review.

<u>NASA Response</u>: NASA concurs and has actions underway. As the SSFP matures, the relationship between program/element offices also is maturing. Cooperation/coordination among and between the organizations continues to improve. Charters for the Safety and Product Assurance Panel, the System Safety Review Panel, and associated subpanels have been proposed for approval by the MS/Deputy Director and should further the amalgamation of the safety and engineering tasks that need to be performed.

Safety and product assurance requirements and process documents are being updated to better fit the needs of the program. Specifically, the overall Safety and Product Assurance Requirements, Section 9 of the Program Definition and Requirements Document (PDRD) (SSP 30000), have been recently revised. The Safety Analysis and Risk Assessment Requirements document (SSP 30309) also has been revised. The Problem Reporting and Corrective Action Procedures (SSP 30223) are currently scheduled for Space Station Control Board (SSCB) action, and NASA will be processing the FMEA Procedures (SSP 30234) within the near future.

Finding #33: Work continues on defining practical contingency models and their effect on overall Space Station Freedom design. Certain attributes of the contingencies may be design drivers as was the case on the Space Shuttle. Emergency operations may dictate requirements such for redundancy, location of equipment, configuration of a rescue vehicle, and design of the caution and warning system.

Recommendation #33: Develop selected scenarios to a sufficient level of detail to identify the significant ground rules and assumptions for this activity. This would include crew and ground responses for immediate safing action, subsequent isolation of the problem, and restorative or rescue actions.

NASA Response: NASA concurs with the finding and has actions underway. Space Station Freedom Contingency Operations Scenarios have been developed by the JSC Operations Integration Office with direct support from mission operations, flight crew operations, and prime contractor personnel. Specific contingencies are identified along with safing and isolation actions. Changes to design requirements are being developed to ensure implementation of identified operations. Contingency Recovery Scenarios are scheduled and will define restoration or rescue actions as required.

Finding #34: There appears to be no standard program-wide list of safety-critical functions for the Space Station Freedom. Such a list is required to support thorough hazard analyses and risk assessment. The crew's ability to egress from the station is an example of a safety-critical function.

Recommendation #34: The Space Station Freedom Program safety and product assurance organization, along with the engineering and operations organizations, should develop a program-wide list of safety-critical functions. Consideration should be given to including waste management in the list.

NASA Response: NASA concurs and is following the recommendation. A list of safety critical functions will be identified in the PDRD prior to the Integrated System PDR.

Finding #35: The Space Station Freedom will be highly dependent upon computers for its operation, and will have a very large complement of software to run them. The hardware and software will have to be upgraded occasionally without being returned to the ground, and flight experiments will require regular changes to the distributed computer system. Original plans for Space Station Freedom software testing included building a large test facility in which software could be tested in an environment that would represent the station.

The test facility apparently has been scaled back by substituting simulation for actual hardware.

Recommendation #35: NASA should institute a full-scale software testing environment for the Space Station Freedom and that facility should include as much actual flight hardware as possible.

NASA Response: NASA concurs with the finding and has actions underway. NASA concurs with the recommendation that a full-scale software testing environment for the Space Station Freedom be developed. NASA also agrees that the facility should include as much hardware as possible to lessen dependence on simulations. Since January 1990, there has been an action underway to consider this issue. A Verification Steering Committee led by the Deputy Manager for Program and Operations is reviewing and assessing the current Space Station Freedom verification approach. One of the areas being worked at this time is that of the necessity and characterization of a central facility for integrated software testing. Funding has been set aside for the construction and outfitting of this facility. A final recommendation is expected by the end of the third quarter of Fiscal Year 1990.

LOGISTICS AND SUPPORT

The Panel is concerned about this area but have not received sufficient information on the logistics associated with assembly and resupply; consequently, there are no findings or recommendations. However, a discussion of this vital program area is found in Section III.

NASA Response: The Space Station Freedom Logistics Program is characterized by a three-phase approach--acquisition, assembly, and operational support. The acquisition phase is managed by the program office and implemented by the design centers. A key function for logistics in this phase is the use of a Logistic Support Analysis process to analyze and influence the hardware for a more supportable and maintainable station. This process is based on a Department of Defense approach that has been tailored to ensure consideration for limited on-orbit resources during the design effort. A logistics panel, chaired by the program office and with members from NASA Centers, international partners, and contractors, is the forum used to integrate the various logistics activities and identify concerns. During this phase, detailed requirements and plans are being put in place to transfer design center logistics responsibilities (spares projection, procurement management, depot maintenance, etc.) to the launch site.

The Space Station assembly and operation era logistics support will be characterized by the human, material, and information resources and associated activities required to transport material to and from orbit, repair and maintain flight hardware, and to repair and maintain the ground systems. The maintenance of program hardware and the resupply/return of consumable supplies, experiment hardware, maintenance and repair materials, tools, manpower, and the transfer of crew personnel will constitute a major portion (at least 50 percent) of the operational era costs.

To manage the operational logistics task, a Logistics Operations Center (LOC) will be established. Reporting to the program office at NASA Headquarters and located at Kennedy Space Center (KSC), the LOC will provide the execution level integration needed to assure total integrated logistics support to the Space Station and to provide strategic, tactical, and execution level planning support to the appropriate levels of management. An onsite intermediate/depot level repair facility will be constructed at KSC to perform failure analyses, manage the repair process, and to recertify station hardware for flight. A program-wide Logistics Information System will allow timely coordination of direct support, planning, and analyses activities among the LOC, Space Station Control Center at JSC, and engineering support centers located at the original design centers.

D. AERONAUTICS

AIRCRAFT MANAGEMENT

Finding #36: *NASA has downgraded the level of the Headquarters Aircraft Management Office. This action has made it more difficult for the Aircraft Management Office to coordinate the development of aircraft operation policy for astronaut training and administrative aircraft.*

Recommendation #36: NASA should reestablish the Headquarters Aircraft Management Office at a level where it can coordinate and establish policy for all types of flight operations throughout NASA.

NASA Response: In its role as the Headquarters focal point for agency-wide aircraft operations and management, the Aircraft Management Office (AMO) in the Office of Management is responsible for the development of policy and oversight of its implementation as regards aircraft acquisition, operation, and maintenance and in the areas of flight crew qualifications and training. The change in management structure was initiated to assure additional senior management daily attention and emphasis on these important policy-making functions and on aviation safety where the Office of Management is responsible for assisting the Office of Safety and Mission Quality (OSMQ) in the development of aircraft safety policy and oversight of its implementation. We know of no cases where this new management structure has made it more difficult for the AMO to coordinate the development of an aircraft operations policy for astronaut training or administrative aircraft as stated in the finding. On the contrary, the additional daily attention provided by the Director, Logistics, Aircraft and Security Office accompanied by the continuing close attention of both the Associate Administrator for Management and his Deputy has expedited the implementation of a major effort to update NASA's aircraft policies. This process has been thoroughly coordinated with both the OSMQ and the institutional program offices and has included several briefings to the new NASA Administrator.

Finding #37: *Flight recorders for nonresearch aircraft again have been removed from the budget because of fiscal constraints. These recorders have been proposed for installation in all nonresearch aircraft (where recorders are not already installed) as a means of accident prevention and as a tool for accident analysis.*

Recommendation #37: Reinstate the program to obtain and install flight data recorders suitable for aircraft trend analysis as well as for accident resolution. Further, a program should be established for regular analysis of the data provided.

NASA Response: The value of flight data recorders as a means of accident analysis is well recognized. The installation of recorders in the JSC's fleet of aircraft that do not already have recorders: 28 T-38's, the KC-135, the Super Guppy, and 2 WB-57 aircraft, is estimated to cost in excess of $1.7 million.

Considering the Agency's overall budget constraints, and in turn the fiscal limitations of the aircraft program, the installation of flight recorders must be weighed against safety requirements and other requirements for improvements and needed modifications for the aircraft. Because of the relatively small and diverse aircraft fleet in NASA, flight recorder usefulness within NASA for trend analysis is uncertain.

Consequently, the value of recorders is recognized but must be prioritized, considering all safety-related requirements.

AERONAUTICAL RESEARCH

There were no findings or recommendations under Aeronautical Research.

E. RISK MANAGEMENT

<u>*Finding #38:*</u> *NASA has taken the position that a lack of maturity, insufficient data base, and lack of funds associated with quantitative risk assessment limits its usefulness during the preliminary design of the Space Station Freedom. Specifically, the Space Station Freedom Program Office is relegating decisions regarding the use of quantitative risk assessment (or similar techniques) to the various work package managers and contractors rather than to institute a common approach.*

<u>*Recommendation #38:*</u> The NASA management should develop and adopt a policy with appropriate methodology for performing quantitative risk assessment at the outset of large space ventures such as the Space Station Freedom Program.

<u>*NASA Response:*</u> NASA concurs and has actions presently underway. The Safety Analysis and Risk Assessment Requirements document (SSP 30309) for the SSFP has been approved by the SSCB and will be presented to the Program Control Board. It establishes a common approach to the use of risk assessment. More specifically, SSP 30309 requires the development of event scenarios (event trees) at the subsystem functional level and at the component failure mode, operations, and crew actions level. These event scenarios are part of the overall safety risk assessment and are developed during design and review phases. Scenarios are quantified when one or more of the following conditions hold:

- There exists significant uncertainty about the severity and/or likelihood of occurrence of a scenario

- A scenario is judged, by qualitative means, to have a catastrophic or critical severity and a high likelihood of occurrence, and has not already become a constraint to flight by a qualitative assessment

- Controls to prevent the hazard scenario are the least effective features of the Hazard Reduction Procedure Sequence (i.e., warning systems for hazard control rather than design for minimum hazard occurrence).

<u>*Finding #39:*</u> *A new contractor has been selected by NASA Johnson Space Center to provide safety, reliability, maintainability and quality assurance support services to the Johnson Space Center. This contractor transition began February 1, 1990. The number of contractor personnel involved is approximately 350, many of whom will be new to the program.*

<u>*Recommendation #39:*</u> NASA management should monitor this changeover closely so that the necessary level and types of service are maintained.

<u>*NASA Response:*</u> NASA fully concurs with the recommendation and has put mechanisms in place to carefully manage and oversee the changeover process. The changeover was initiated by the normal Government competitive procurement process in which Ford

Aerospace Corporation was selected to replace the long-term incumbent (Boeing Aerospace Operations). The loss of continuity was a concern to JSC management when the selection was made, and several actions were put into place to closely monitor and manage the contractor transition process.

Beginning about 5 weeks before the transition was to officially take place, a weekly review of transition planning and implementation activities with the Director and key staff of the Safety, Reliability, and Quality Assurance (SR&QA) organization was established. The purpose of this weekly review was to stay abreast of any problems or issues that came up during the transition process and to be able to quickly resolve stumbling blocks or problems dealing with the actual transition activities. Detailed schedules were developed to maintain control and status of the actual work. At these meetings, priorities were set to ensure that any effort needed to continue to support Space Shuttle flight preparation activities was in place and was being accomplished on a timely basis. Management from all functional areas of both the support contractor and NASA participated and worked together as a team to resolve any issues identified. These formal weekly reviews continued until May 3, 1990, wherein most of the significant transition issues were closed, and any open work remaining was placed on the weekly review of the SR&QA product and task schedules.

Another more detailed team was established to define all of the task orders that assign work to the support contractor and to deal with the very detailed transition issues associated with work processes. This, too, is a joint activity between NASA and the contractor. This activity is still in place with the current plan to have completed all the detailed work in the July 1990, time frame and is going well. Since the formal transition was initiated on February 1, 1990, the new contractor has successfully supported two Space Shuttle flights, as well as the preparation activities for the succeeding flights. In addition to the intensive effort provided to facilitate the transition, JSC SR&QA management conducts monthly formal Technical and Management Review meetings with the contractor management to go over the performance evaluation of the contractor for that month. A comprehensive evaluation by NASA, with a self evaluation by the contractor, is made of all task orders each month. The Director, SR&QA, makes regular reports on the progress of the contractor transition to the JSC Center Director, to provide additional management visibility.

NASA believes that the proper mechanisms have been put in place and that adequate attention is being paid to this very important contractor changeover.

Finding #40: *There is a need to monitor the aging and reliability of components as a function of time in service. Typically, monitoring is accomplished with fleet leader statistics. Unfortunately, as presently employed, fleet leader numbers can be relatively uninformative or even misleading. For example, these data do not permit managers to assess whether the fleet leader is representative of the entire system or simply an outlier.*

Recommendation #40: Statistics on single fleet leaders should be augmented by simple data that identify the distribution of the entire fleet. For items that have been procured in relatively large numbers, this might be expressed as percentages. For relatively unique items, information on the three or four of the oldest and youngest items might be provided.

NASA Response: NASA agrees. Historically, fleet leader statistics were used almost exclusively; however, this is not the case today. The SSME is the only item using a modified fleet leader concept in that it uses multiple fleet leaders to obtain a more representative sample of the fleet distribution. This minimizes the likelihood of a single fleet leader being an outlier. Use of a single fleet leader is atypical rather than typical. Fleet leader information is supplemented by such techniques and data sources as stress analysis, fracture analysis, qualification test results, life limit tests, and additional inspections of critical hardware. The process is no longer restricted solely to the fleet leader statistics. Initially, the fleet leader is the prime source of data defining the anticipated fleet distribution. However, as additional devices are built, tested and put into operation additional data becomes available to "temper" the initial judgement of the initial fleet distribution. Information is retained at the contractors on each device and these statistics are compared using in-house studies to guide judgement on retention of items and the flight worthiness of them. These data are reviewed prior to each flight and bear heavily on the decisions to retain/reuse items and on the ultimate launch decision.

C. AEROSPACE SAFETY ADVISORY PANEL ACTIVITIES

FEBRUARY 1990 - JANUARY 1991

FEBRUARY

7-10	-	STS-32 Flight Readiness Review, Kennedy Space Center
13-14	-	Space Station Advisory Committee Meeting, Washington, DC
20-22	-	STS-32 Launch-2 and -1 Day Reviews, Kennedy Space Center
21-24	-	Aerospace Medicine Advisory Committee Meeting, Johnson Space Center
21	-	Space Station Hearing/Chm Nelson, Washington, DC
23	-	Alternate Turbopump Programs by Pratt & Whitney, West Palm Beach, FL
27	-	Intercenter Aircraft Operations Panel Meeting, Lancaster, CA

MARCH

9	-	Congressional Staff, Washington, DC
9	-	Space Shuttle Main Engine, NASA Headquarters
22	-	Space Station Work Package #4, Rocketdyne, Canoga Park, CA

APRIL

5	-	Space Shuttle and Space Station Computer Issues, Johnson Space Center
11	-	Human Performance Research Laboratory Activities, Ames Research Center
13	-	Aerospace Safety Advisory Panel Annual Meeting, NASA Headquarters
26-27	-	Tethered Satellite System, Marshall Space Flight Center

MAY

1	-	SSME Turbopump, Aerojet Corp., Cleveland, OH
2	-	Human Performance, Ames Research Center
4	-	Office of Management and Budget, Washington, DC
8-9	-	Space Station Work Package #1, Boeing Space Co., Huntsville, AL
10	-	Space Shuttle Main Engine, Marshall Space Flight Center
10	-	Human Performance, NASA Headquarters

JUNE

11-13	-	Bio-Med Meeting, Aerospace Medicine Advisory Board, Washington, DC
19-20	-	Office of Space Flight Review of Space Shuttle and Space Station, NASA Headquarters/Reston
26-28	-	Alternate Turbo Pump Development Program, Pratt & Whitney, West Palm Beach, FL
26-28	-	Army/Navy/Air Crew/Aircraft Integration Program Activities, Ames Research Center

JULY

16-18	-	26th AIAA/SAE/ASME/ASEE Joint Propulsion Conference, Orlando, FL
18	-	Space Station Work Package #4 Review, Lewis Research Center
25-27	-	OAET and OSSA Activities, NASA Headquarters

AUGUST

3	-	Space Station Work Package #4, Lewis Research Center
8-9	-	GPC and SE&I, Johnson Space Center
16-17	-	Aeronautical Activities, Langley Research Center
22-24	-	Manned Space Activities, Johnson Space Center

SEPTEMBER

12-13	-	GPC Memory and SE&I, Johnson Space Center
24-28	-	Aeronautical, Human Performance, Space Activities, Ames Research Center

OCTOBER

30-11/2	-	Shuttle Launch and Landing Processing, Kennedy Space Center

NOVEMBER

2	-	Shuttle/Station Logistics, Kennedy Space Center
13-14	-	Advanced Solid Rocket Motor, Marshall Space Flight Center
14	-	SSME, Marshall Space Flight Center
13-15	-	Aviation Safety Reporting System Symposium, Reston, Virginia

DECEMBER

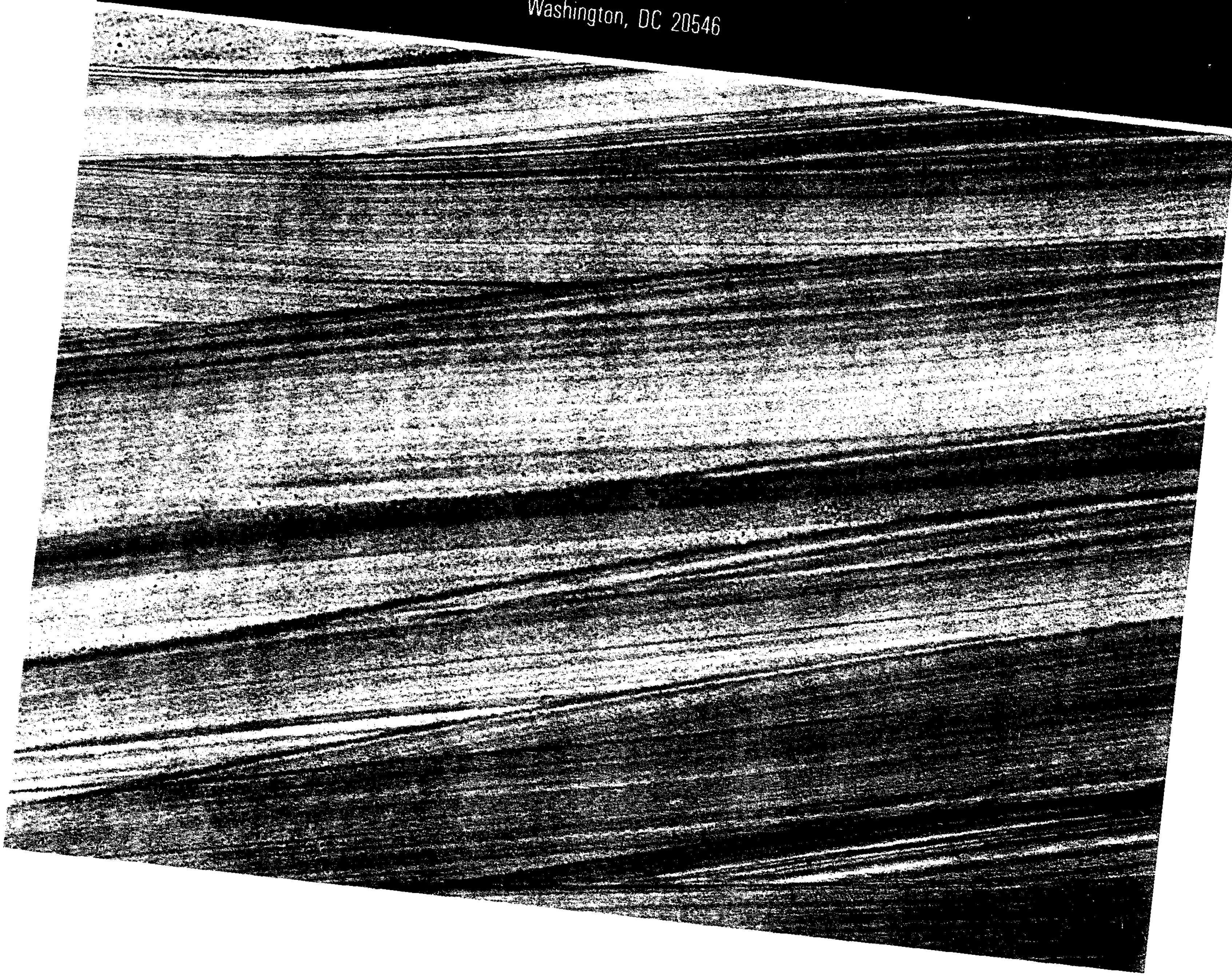
4-7	-	Safety and TQM Activities, Stennis Space Center and Michoud Assembly Facility
20	-	Aircraft Operations, NASA Headquarters

JANUARY

3	-	Aircraft Operations, NASA Headquarters
8	-	Shuttle Processing Operations, Kennedy Space Center
15	-	Congressional Staff, Washington, DC

For Further Information
Please Contact:

Aerospace Safety Advisory Panel
NASA Headquarters
Code Q-1
Washington, DC 20546



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