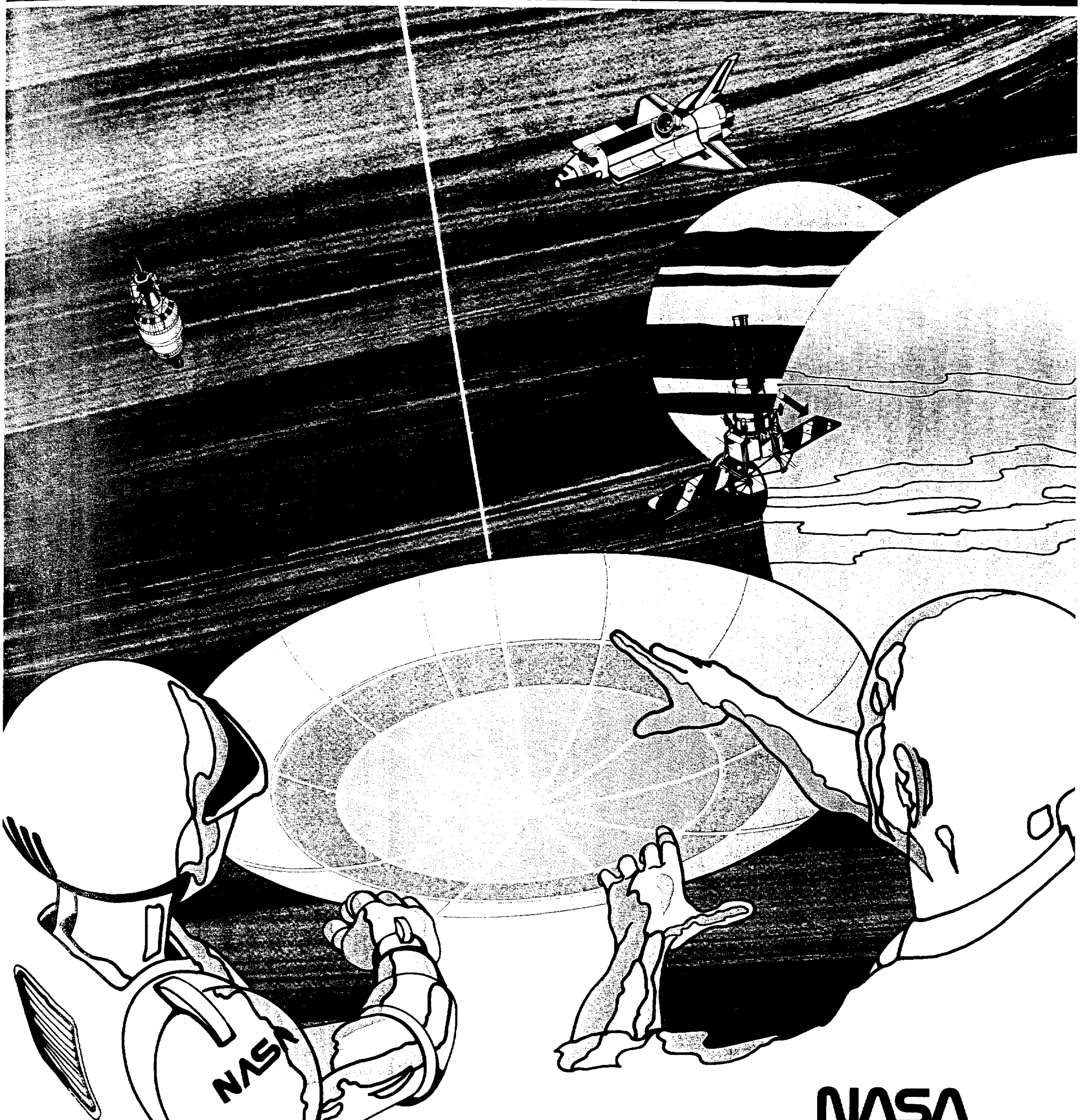
ANNUAL REPORT

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.

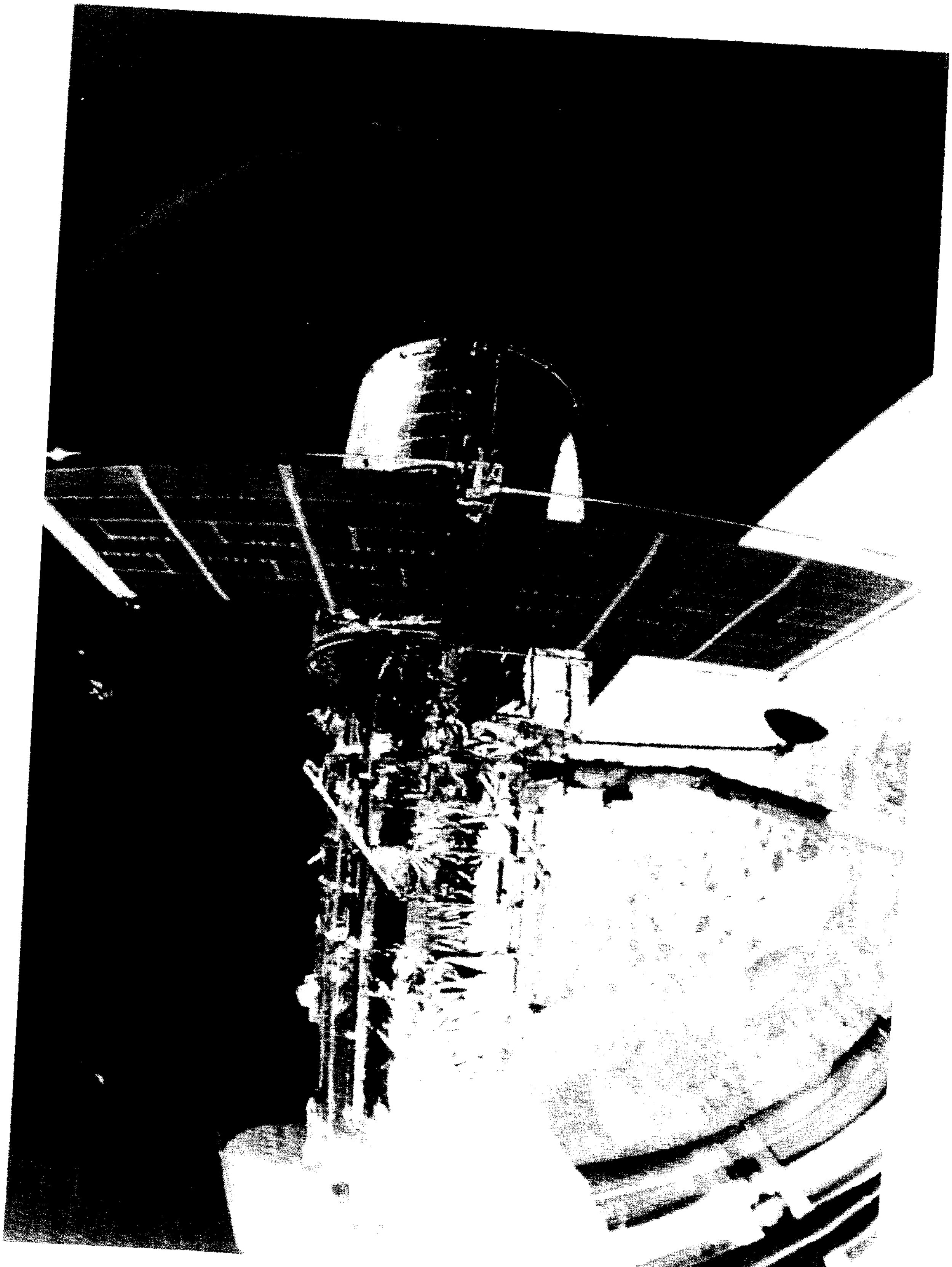
Mishap Reporting: The implementation of NASA Management Instruction 8621.1E "Mishap Reporting and Investigation" presents a comprehensive implementation approach to reporting and investigation procedures. However, the more extensive use of human factors expertise and the formal investigation of "close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

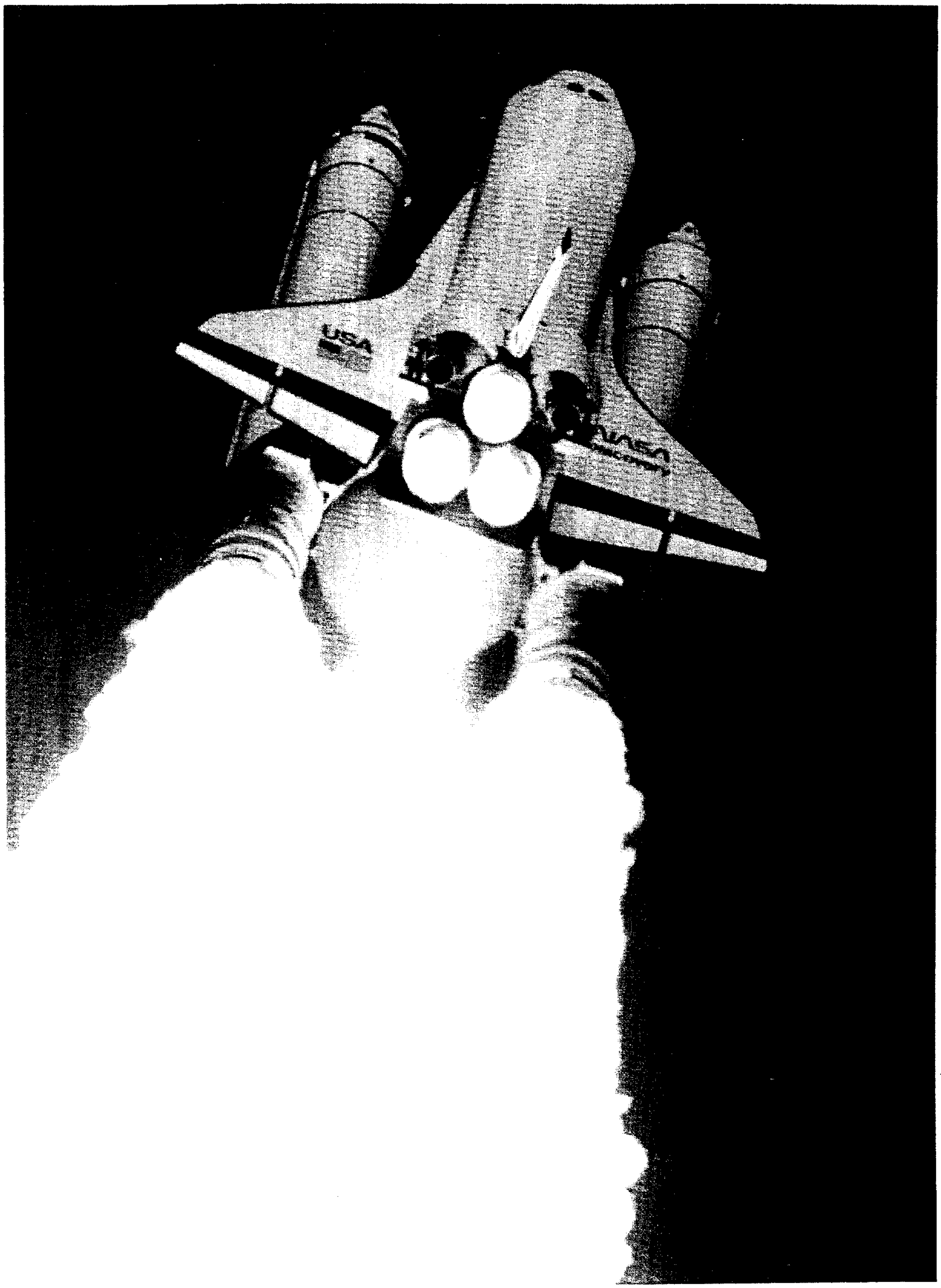
INTRODUCTION

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.

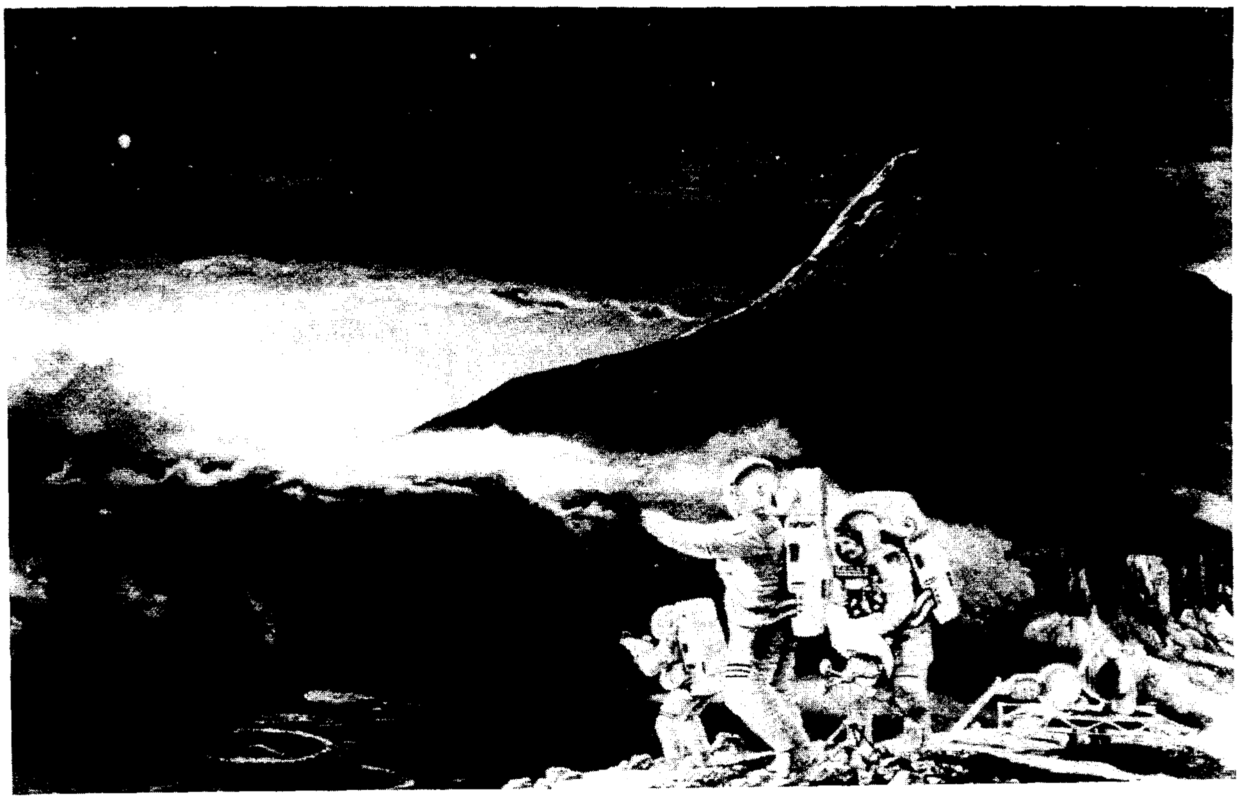
Recommendation #25: To help ensure structural integrity of each vehicle, much greater effort must be devoted to these tasks. A comprehensive program should be developed for the orderly overhaul of Orbiters that are expected to operate into the 21st century.

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

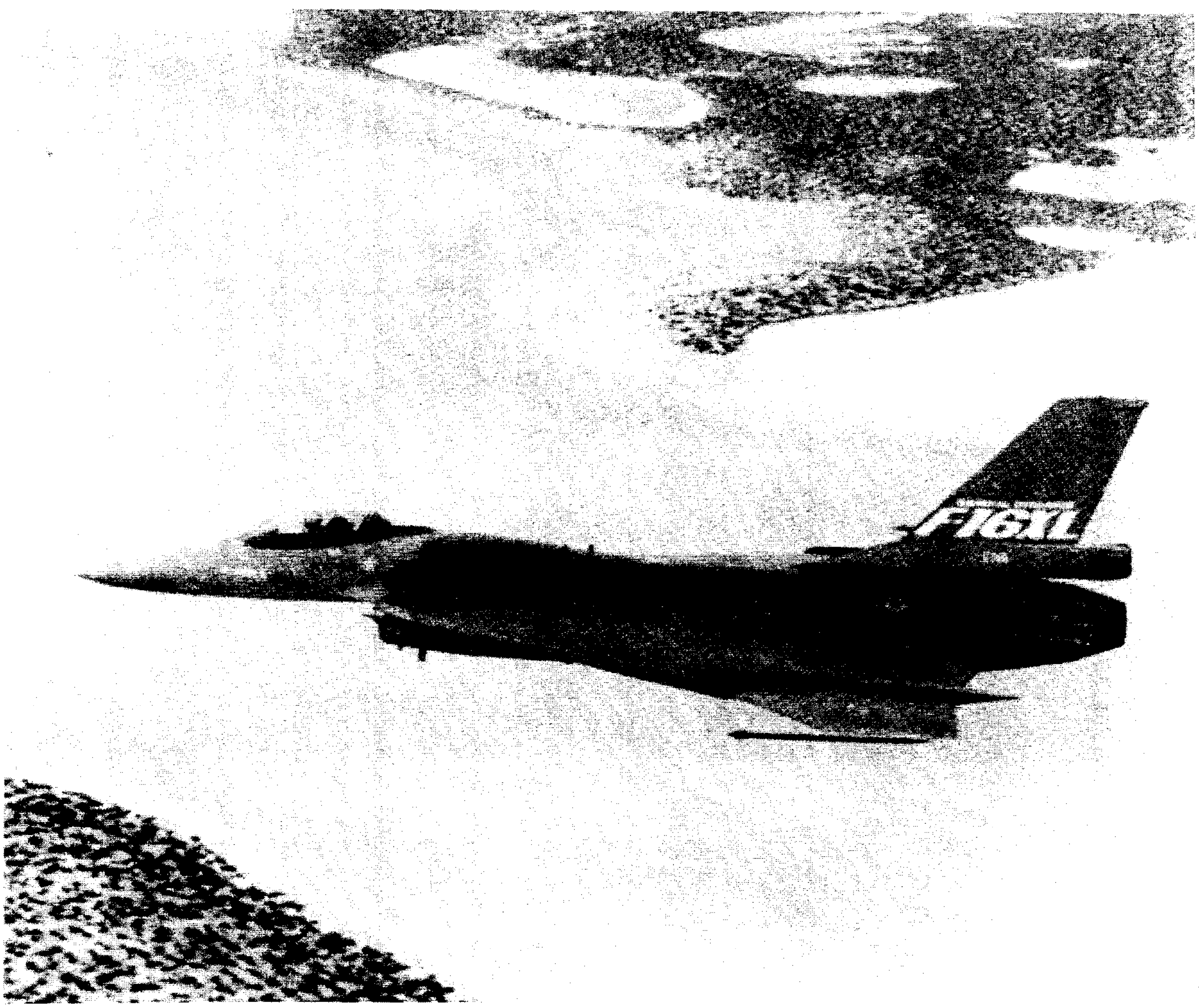
Finding #27: Past ASAP reports have cited concerns over the extent of Headquarters involvement in aircraft operations safety. During the past year, a reorganization and redelineation of Headquarters safety responsibilities has gotten underway.

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

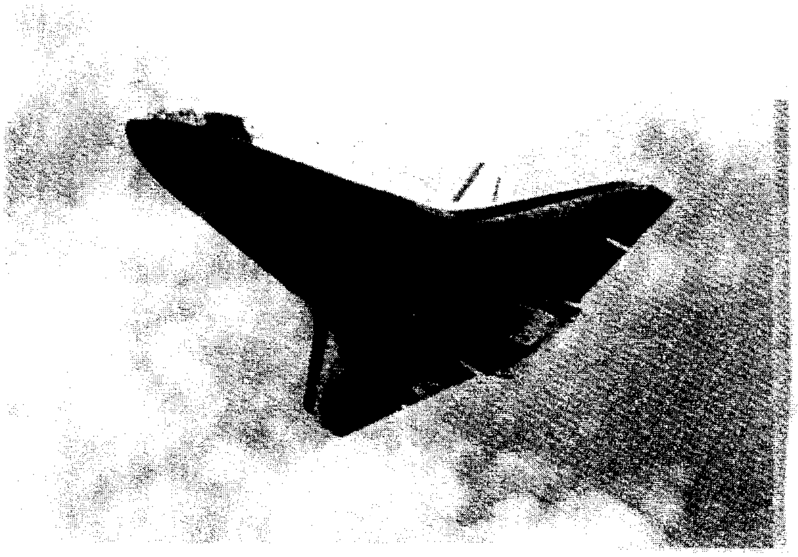
Finding #33: NASA's current plans for Space Station and the Space Exploration Initiative will inevitably involve the need for both planned and contingency extravehicular activities (EVA).

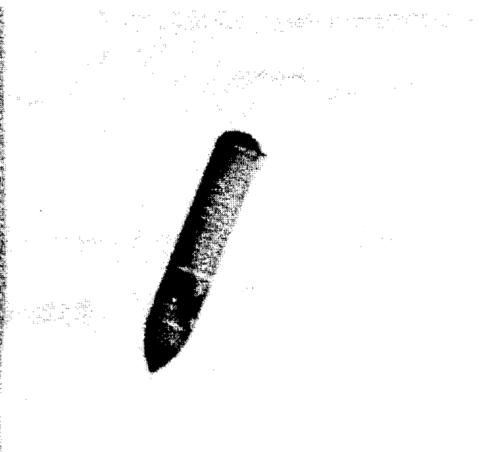
Recommendation #33: The planning and design for Space Station and other manned space exploration programs should make every attempt to minimize dependence on EVA. In addition, NASA should undertake the development of an improved Extravehicular Mobility Unit that eliminates or reduces the maintenance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

High-Pressure Oxidizer Turbopump (HPOTP): 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.

High-Pressure Fuel Turbopump (HPFTP): 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.

Gaseous Oxygen Heat Exchanger: 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.

Two-Duct Powerhead (Phase II+): 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:

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

- Hydrocleaning. Except for sensing, the satisfactory completion of the job is another matter.

- A Continuous Propellant Mixing and Casting. 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