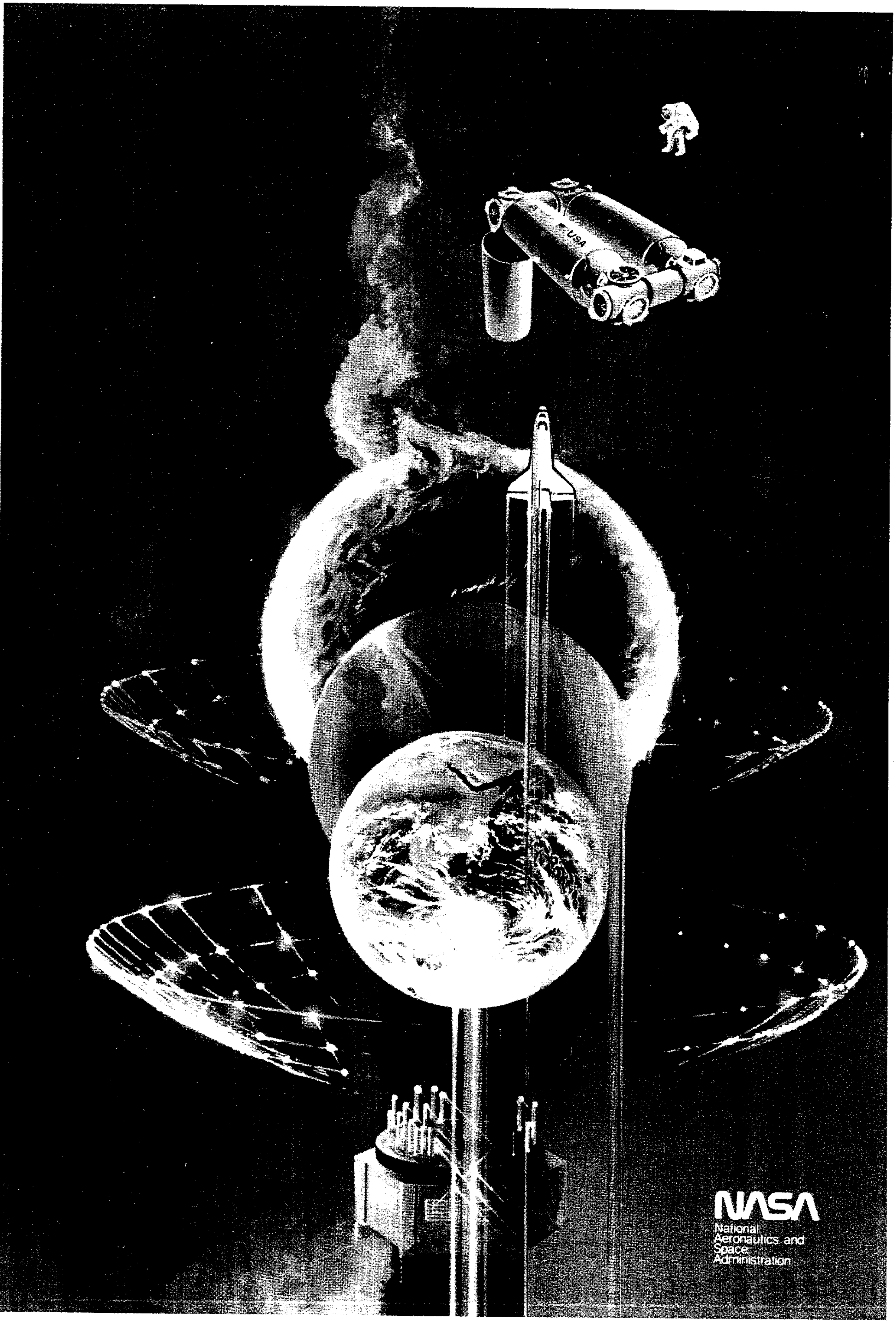
AEROSPACE SAFETY ADVISORY PANEL

ANNUAL REPORT MARCH 1990



NASA

National
Aeronautics and
Space
Administration

NASA

National Aeronautics and
Space Administration

Washington, D.C.
20546

Reply to Attn of: Q-1

March 1990

Honorable Richard H. Truly
Administrator
National Aeronautics and Space Administration
Washington, DC 20546

Dear Admiral Truly:

The Aerospace Safety Advisory Panel is pleased to present its annual report to you. This report provides findings, recommendations and supporting material regarding the Space Shuttle, the Space Station Freedom, aeronautics, and other NASA activities. The period covered in this report is from February 1989 through January 1990. The Panel requests that NASA respond only to Section II, "Findings and Recommendations."

The main focus of the Panel during the past 18 months has been, and continues to be, monitoring and advising NASA and its contractors on the Space Shuttle Program with increasing attention being given to the Space Station Freedom Program. As before, we are also attending to those significant areas of NASA's aeronautical projects such as the X-29.

It is now 18 months since the flight of Discovery (STS-26) which launched the effort referred to as "The Safe Return to Flight" following the Challenger accident. Eight flights of the Space Shuttle have now been conducted.

The Panel believes NASA has learned much from the Challenger experience. The management organization is well defined. Communications up and down the line are disciplined and effective. Launch procedures are controlled with good discipline. The Safety, Reliability, Maintainability and Quality Assurance organization is making its presence felt. If the current management environment is maintained, the Panel believes NASA can go a long way towards achieving a goal of increased Space Shuttle flight rate--while being ever vigilant in maintaining an attitude of "safety first."

NASA faces a heavy work load on both the Space Shuttle and the Space Station Freedom Programs. As with all national programs, this effort will be conducted with severe budget restraints. This is why the Panel recommended in its March 1989 report that an independent review of the Advanced Solid Rocket Motor Program be conducted. Our major concern still is that this expensive program will detract from other more critical efforts to reduce risk on both the Space Shuttle and Space Station

Freedom Programs. This position received a full airing when we presented our March 1989 report and also at the hearing of the Congressional Subcommittee on Space Science and Applications on September 28, 1989. It is our understanding that Congress will direct a review of the Advanced Solid Rocket Motor Program by a panel from the National Research Council.

In its March 1989 report, the Panel stated "The NASA Space Shuttle organization in conjunction with its prime contractors should be encouraged to continue development and incorporation of appropriate design and operational improvements which will further reduce risk." The Panel was encouraged when NASA developed the proposed Assured Shuttle Availability Program. The goals of this program are the enhancements of Space Shuttle safety and operability. We hope that NASA top management encourages this effort--monitoring it to achieve timely results of lower program risks. This program has been too long in coming. To conduct the hundred or so flights required to achieve the planned NASA programs, including the construction of the Space Station Freedom, without further reducing risks, will probably entail the loss of another Space Shuttle. This conclusion was also reached in a report by the Office of Technology Assessment titled "Round Trip To Orbit," issued in the fall of 1989 and presented to Congress at that time.

NASA should adopt the attitude that another Challenger accident can not be allowed to happen--even though it is acknowledged that the Space Shuttle is a high risk program. NASA should do everything reasonable to see that another major accident does not happen. Critical hardware items that could be modified to reduce risk have been allowed to persist without changes. For example, major risk reducing changes to the Space Shuttle Main Engine have been studied since 1973 without being incorporated in these main engines--even though the main engines are considered to be the highest risk component of the Space Shuttle system.

It is the opinion of this Panel that NASA top management should make up for lost time. If risks are not further reduced, another Space Shuttle accident will most likely occur. The impact on NASA and the nation's space program would be calamitous. NASA now has a competent and effective organization capable of continuing the successes achieved since the commencement of "The Safe Return to Flight." Hopefully, with an aggressive risk reduction program, NASA can extend this success through the next hundred flights and through the critical period of the construction of the Space Station Freedom without another major accident.

The Panel's March 1990 annual report discusses its findings and recommendations, all aimed at risk reduction. The Panel stands ready to assist NASA in continuing the exciting space programs with increased safety.

As always, it has been our pleasure to work with the people of NASA and the contractor personnel supporting NASA, and we want to take this opportunity to thank them all.

Sincerely,

Joseph F. Sutter

Joseph F. Sutter
Chairman
Aerospace Safety Advisory Panel

Enclosure

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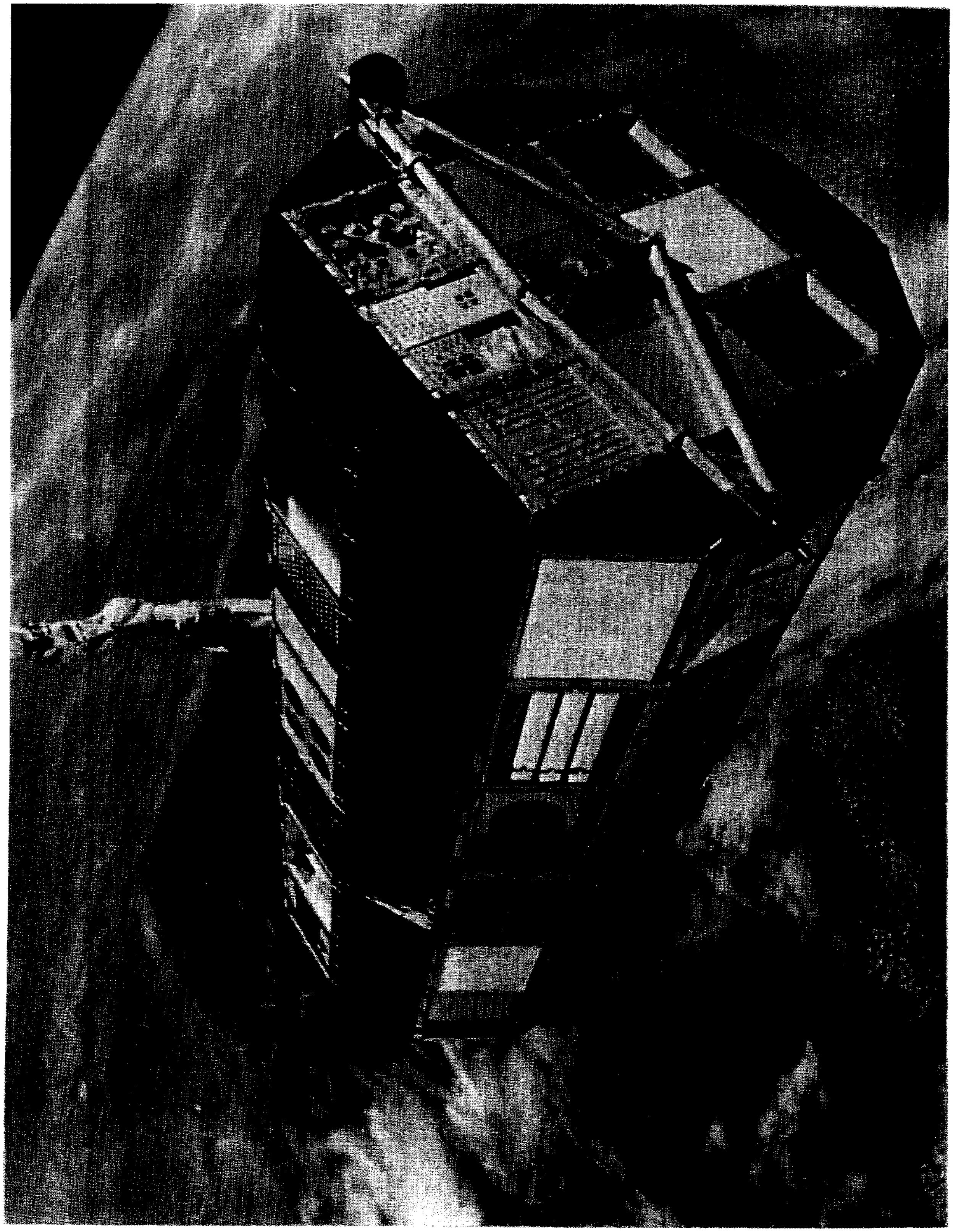


I. INTRODUCTION

I

INTRODUCTION

The pace of activities at NASA and its many contractors has been increasing steadily during the past year in both the highly visible manned Space Shuttle and Space Station Freedom Programs as well as the unmanned missions such as the Cosmic Background Explorer, Galileo to Jupiter, and Magellan to Venus. Also active are the aeronautical flight research and development projects such as the X-29, F/A-18, and the CV-990 for testing of the Space Shuttle orbiter tires and braking. The Aerospace Safety Advisory Panel (ASAP) continued its multifaceted fact-finding sessions (43) to examine safety and safety-related aspects of many of these flight programs. As always, the Panel has given priority to those programs that involve the safety of manned space flight.

As a result of last year's annual report, dated March 1989, there was a great deal of interest generated in the Advanced Solid Rocket Motor (ASRM) Program. It was a major topic during the Panel's testimony before the Senate Subcommittee on Science, Technology, and Space on May 11, 1989; and before the House Subcommittee on Space Science and Applications on September 28, 1989. NASA's response to the Panel's annual report recommendation regarding the ASRM Program is found in Section IV.B., page 5. The Panel will continue to review the Advanced Solid Rocket Motor in the same light as other Space Shuttle elements (Orbiter, Space Shuttle Main Engines, Redesigned Solid Rocket Motor, External Tank, and the Launch Processing System). This report includes comments based on recent briefings and discussions with NASA and contractor personnel.

The overall discipline of risk management has been an area of heightened attention for the Panel during this past year. The Panel reviewed the management process by which the safety risks can be brought to levels or values that are acceptable to the final approval authority. Risk management includes establishment of acceptable risk levels, assessment of existing risks, and institution of changes in system design or operational methods to achieve such risk levels. Supporting Space Shuttle risk reduction is the proposed Assured Shuttle Availability Program initiated by NASA's Office of Space Flight. The goals of this program include improving safety and reliability, accounting for obsolescence, and reducing mission cost--all of which the Panel heartily endorses.

The Panel also endorses the current efforts by NASA and its contractors to establish practical methodologies to quantify results of risk assessments. This will permit a more rigorous determination of the relative benefits of alternative or proposed safety/reliability enhancements. This is in line with recommendations made by the Panel in prior annual reports as well as during testimony before the House and Senate Subcommittees.

Additionally, NASA is seeking new technologies that may further enhance safety. Within NASA's Civil Space Technology Initiative (CSTI) conducted under the auspices of the Office of Aeronautics and Space Technology, activity is devoted to booster technology that is directed toward the development of a data base (hardware analysis and testing) to allow improved Space Shuttle launch safety and reliability. Another goal is to reduce hazardous environmental conditions that result from the combustion of current solid rocket propellants (hydrochloric acid and aluminum particulates). This propulsion technology program includes both hybrid technology (liquid oxygen and separate solid fuel with no oxidizer), and liquid oxygen/liquid hydrogen pump and pressure fed booster systems. The Panel feels that these activities should receive specific attention to assure that in the future the United States will have a clean burning booster with improved safety and payload performance.

NASA is in a period that requires, more than ever, that the Congress and NASA management work together in a realistic manner to continue achieving safe and successful manned and unmanned aerospace missions. Some important areas that must be considered include:

- Severe national budget problems are impacting NASA programs.

- The period of "safe return to flight" after the Challenger accident has reached 18 months, with eight successful missions completed. NASA is now embarked on an intensive Space Shuttle Program, with up to 13 missions planned per calendar year by 1993.

- Currently, there is a concerted effort to reduce Space Shuttle ground turnaround time to meet the 13 missions per year schedule. This effort must be conducted with great care.

- There has been a loss of a great many knowledgeable and experienced technical people and managers during the past year. This puts a strain on senior and mid-level managers to meet the technical and managerial demands of the current NASA environment.

- The Space Station Freedom is totally dependent on the use of the Space Shuttle for its construction, supply, and operation.

- There are no <u>firm</u> plans to augment the Space Shuttle capability with an <u>unmanned</u> heavy-lift launcher (such as the Shuttle "C" vehicle).

All of these areas should receive attention during the coming year.

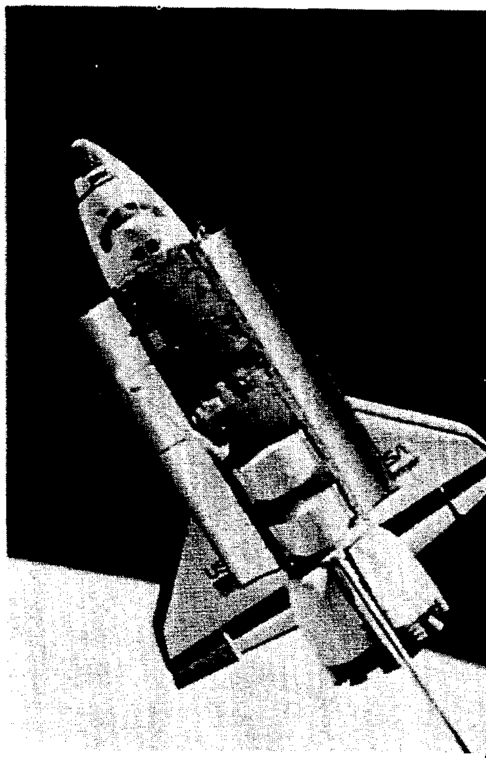
There has been one change to the makeup of the Panel during the previous year. Mr. Gerard W. Elverum, Jr., Vice President and General Manager, TRW Applied Technology Division, completed his service as a Panel member (1982-1989). Mr. Elverum is retained as a consultant to the Panel, thereby securing his experienced support.

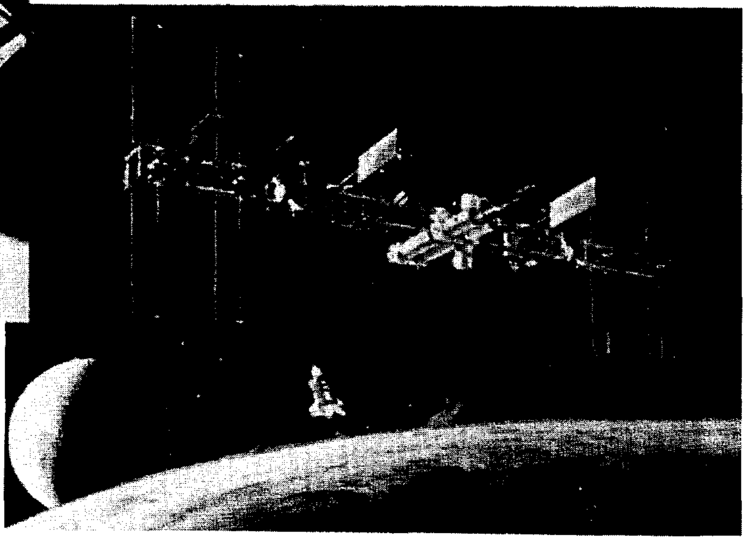
The Panel believes that it is worthwhile to restate its charter:

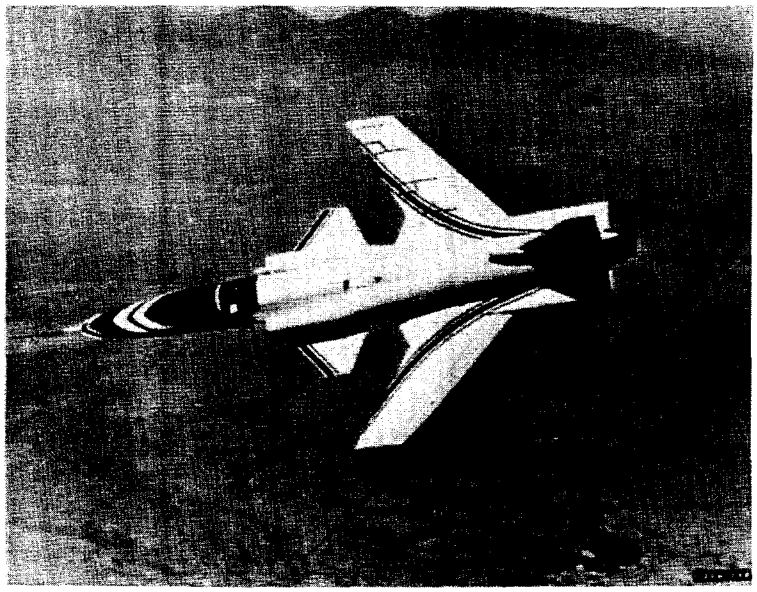
We are to advise the NASA Administrator and Congress on issues of safety throughout NASA. These safety issues encompass both systems and operational safety. To accomplish this advisory role we identify, review, and evaluate critical safety issues by means of direct fact-finding of both NASA and contractor organizations; and provide the NASA Administrator and Congress with our judgments, advice, and recommendations.

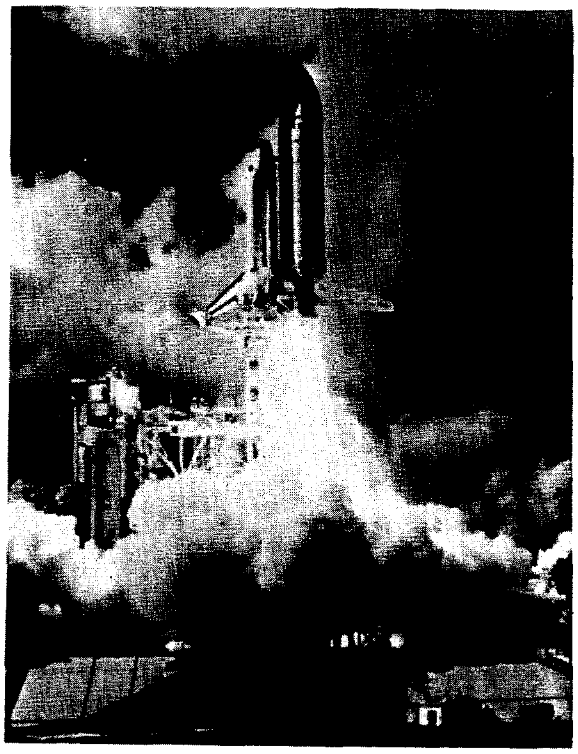
As advisors, we expect--and continue to have--access to all elements of NASA and appropriate areas of NASA contractors. Similarly, we expect that information on problem areas will continue to be provided voluntarily rather than having to be ferreted out by the Panel. The Panel does not have the number of personnel or time needed to obtain the depth of technical insight into a specific program that a manager has. Therefore, we cannot provide the final "go" or "no go" for a specific mission. In addition to undertaking specific assignments or investigations as requested by the NASA Administrator, Deputy Administrator and Congress, the Panel: (1) continuously examines the technical management capability of NASA programs from a safety/reliability viewpoint to assess their strengths and weaknesses; (2) selects a small number of specific program/project functional hardware/software areas and assesses their worthiness with regard to safety/reliability; (3) reviews and assesses those judgments rendered by internal and external review groups; and last but not least, (4) acts to cause NASA and its contractors to be introspective regarding critical hardware/software systems and subsystems, and the decisions affecting them.

The Table of Contents for this annual report identifies the major areas of interest for the Panel during the past year. The Panel has conducted fact-finding sessions at each Level III work package and at the Kennedy Space Center, which has responsibility for final hardware processing leading to the multiple launches required to achieve permanent manned capability as well as the all-up configuration.









II. FINDINGS AND RECOMMENDATIONS

II

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.

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.

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.

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.

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.

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 timeframe 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.

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.

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.

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.

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.

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.

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.

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

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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 dock 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.

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.

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.

Finding #31: 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.

Recommendation #31: 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.

Finding #32: 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.

Recommendation #32: 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.

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.

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.

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.

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.

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.

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.

AERONAUTICAL RESEARCH

There are no findings or recommendations; however, pertinent comments are provided in Section III.

E. RISK MANAGEMENT

Finding #38: 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.

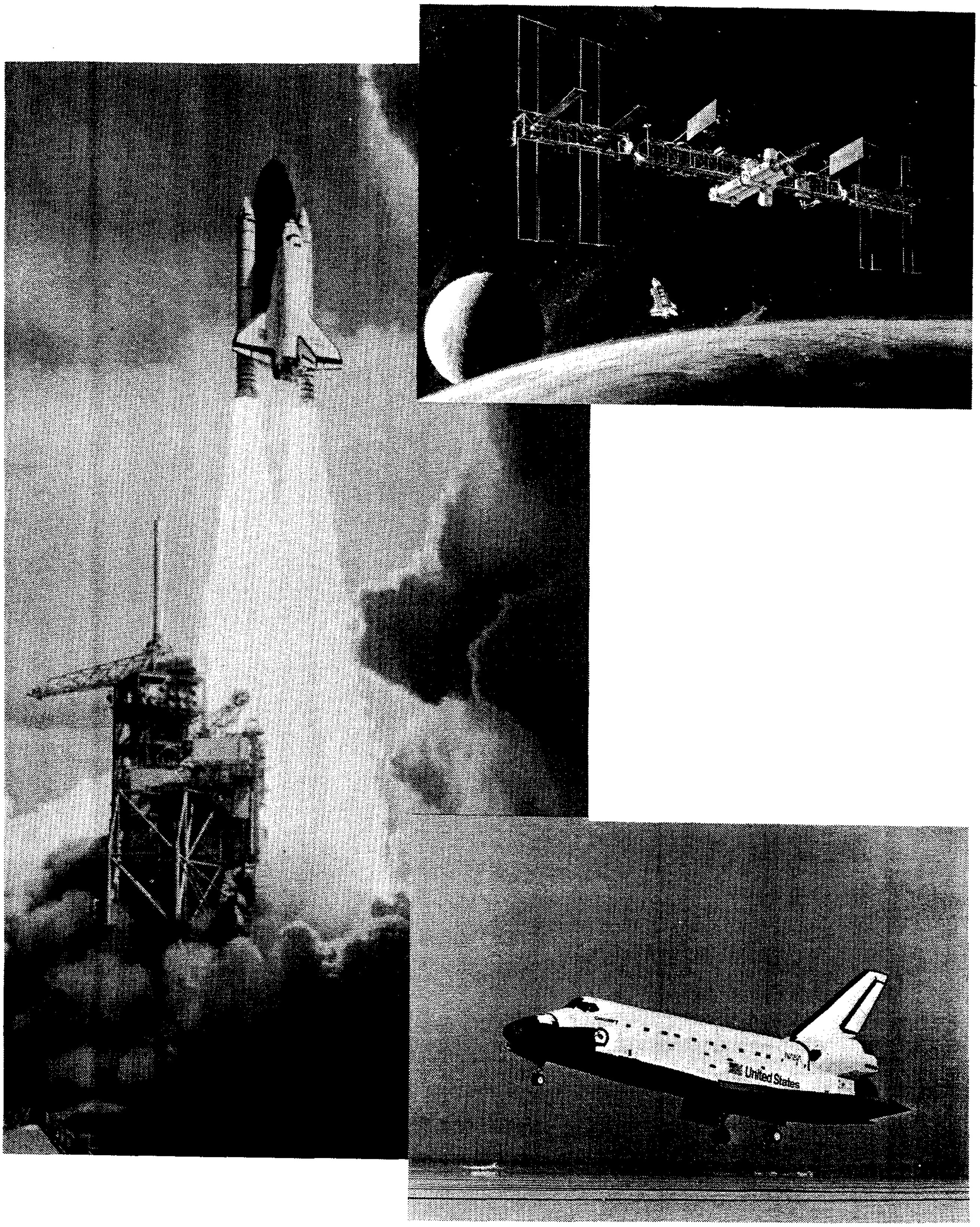
Recommendation #38: The NASA management should develop and adopt a policy with appropriate methodology for performing quantitative risk assessment at the outset of large space ventures such as the Space Station Freedom Program.

Finding #39: 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.

Recommendation #39: NASA management should monitor this change over closely so that the necessary level and types of service are maintained.

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.



III. INFORMATION IN SUPPORT OF FINDINGS AND RECOMMENDATIONS

III

INFORMATION IN SUPPORT OF FINDINGS AND RECOMMENDATIONS

A. OFFICE OF SPACE FLIGHT

MANAGEMENT

(Ref: Findings #1 and #2)

In November 1989, the Office of Space Flight and the Office of Space Station were consolidated into one office--the Office of Space Flight. Dr. William B. Lenoir, a former astronaut, was appointed Associate Administrator for Space Flight with George Abbey as Deputy Associate Administrator. Thomas Utsman, formerly of the Kennedy Space Center, has been brought to Headquarters as Deputy Associate Administrator for Management. The Office of Space Flight is now composed of four major areas: Space Shuttle, Space Station Freedom, Flight Systems, and Institutions (Figure 1).

The consolidation resulted in no major changes to the structure of the Space Shuttle organization. There have been

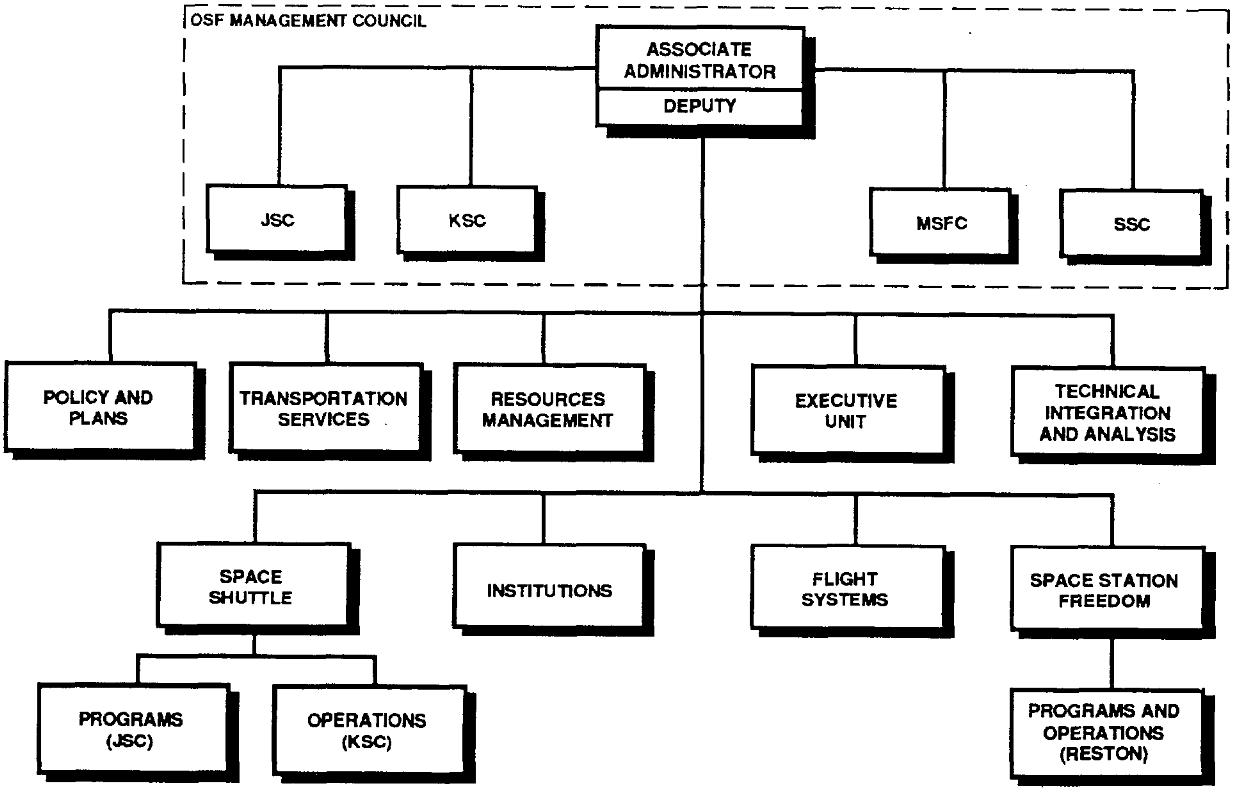


Figure 1, Office of Space Flight

personnel changes in key management positions. Captain Robert L. Crippen, USN, has assumed the position of Space Shuttle Program Director, replacing Arnold D. Aldrich who has been named Associate Administrator for the Office of Aeronautics and Space Technology. Colonel Brewster H. Shaw, Jr., USAF, an astronaut who has flown on two Space Shuttle missions, has replaced Captain Crippen as the Deputy Director, Space Shuttle Program Operations.

Space Station Freedom management has been strengthened. Richard H. Kohrs has been named Program Director. His office, located at NASA Headquarters, lists three major functions: engineering, operations, and policy (Figure 2). Deputy Director, Robert Moorehead, is stationed at Reston, Virginia; and a Deputy for Integration is located at the Johnson Space Center where he can draw on its engineering resources. A similar field office for integration has been established at the Marshall Space Flight Center. Mr. Kohrs has outlined a Space Station Freedom Program review plan (Figure 3) that should provide visibility in a timely manner to NASA top management.

The organizational changes for the Space Station Freedom addresses the issues that have concerned the Panel and have been commented upon in prior annual reports. In particular, the need to provide: greater Level I direction to the Space Station Freedom Program and a strengthened Level II integration function, has been evident for some time. The growing crisis of attracting and developing trained scientists and engineers to sustain the space program into the next century has been noted by the Panel.

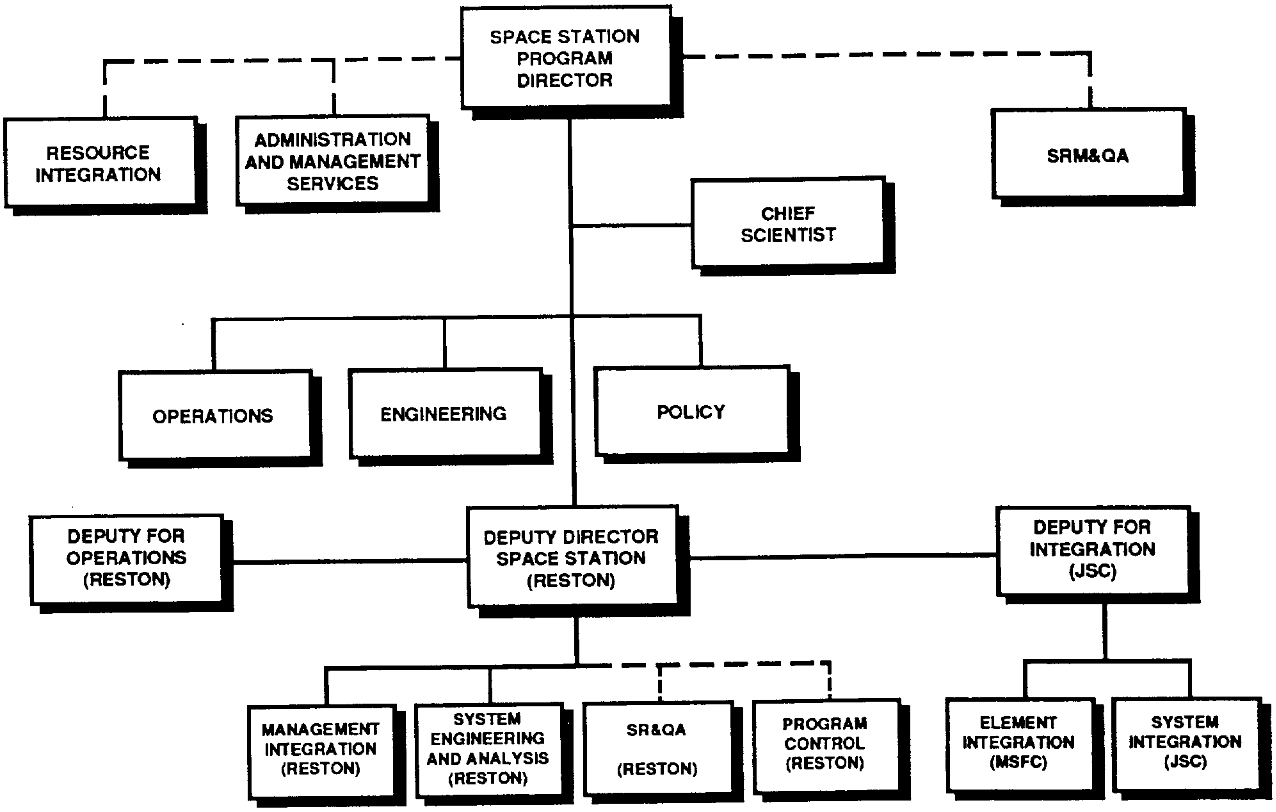


Figure 2, Space Station Freedom

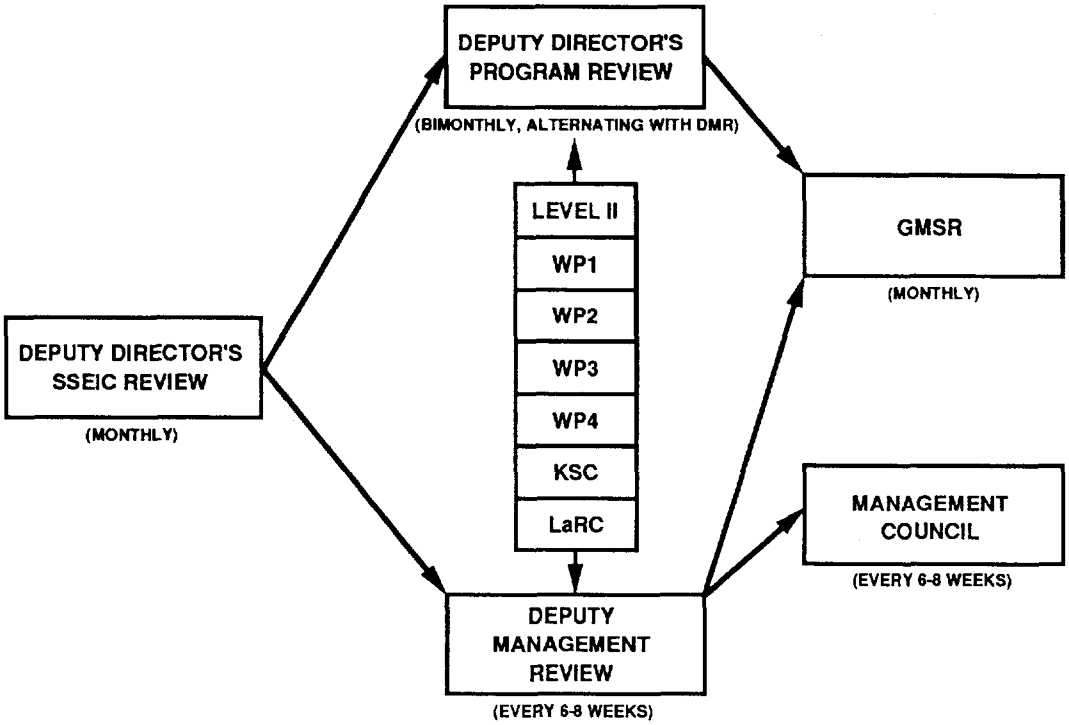


Figure 3, Space Station Freedom Program Review Plan

NASA, the Administration, and the Congress should provide visible and consistent support of the newly consolidated Office of Space Flight and its managers. This support must ensure that program controls truly reside at the program directors' offices at NASA Headquarters to channel the talents and energies of the NASA Centers in a coherent, complementary, and integrated fashion.

The management focus provided by the Deputy Director for Space Shuttle Operations has demonstrated its importance. Channeling all mission-related activities through this individual has provided the communications and information linkages that were not present prior to the STS-51L mission. These linkages are essential if NASA is to maintain acceptable levels of risk in Space Shuttle operations as the flight rate increases in the coming year.

In addition, every effort must be made to achieve greater funding stability to eliminate the annual budgetary see-saw that has immensely complicated management of the Space Shuttle and Space Station Freedom Programs. The goal must be to achieve multiple-year funding for long-duration research and development, and operational space activities.

Positive and aggressive steps are being taken to implement the responsibilities for Level I and II. Major revisions and new issuances of the top-level controlling documents are underway. While the reorganization and reshaping of the Space Station Freedom is not complete, the steps taken by the revamped Office of Space Flight are encouraging and promise to lead the Space Station Freedom Program out of the morassy state it has been in. It is noteworthy that Center Directors and the Management Council have an increased role in supporting the program and assisting with the resolution of any technical and managerial conflicts.

FLIGHT READINESS REVIEWS

(Ref: Finding #3)

The return-to-flight of the Space Shuttle was the culmination of years of intensive effort by everyone involved in the program. Virtually all possible safety aspects were scrutinized to ensure that every possible action to reduce risk was accomplished. Particular emphasis was placed on management communications and reviews because of the role that inadequate communication had played in the Challenger accident.

The extreme intensity of the prelaunch reviews and analyses for the initial Space Shuttle flights were possible, in part, because of the relatively long periods of time between flights. This provided NASA managers with the ability to conduct almost all prelaunch reviews on a face-to-face basis. Thus, readiness reviews were conducted at the Kennedy Space Center for the major milestones in each launch flow such as when the orbiter is rolled out from the Orbiter Processing Facility and when the external tank is mated with the solid rocket boosters. Together with the flight readiness reviews, and those taking place 1 and 2 days before launch (L-2 and L-1), milestone reviews afforded program managers the opportunity for direct interpersonal communications at least five times for each launch.

Since the successful return-to-flight, a marked increase in flight rate has occurred. With flights scheduled to approach a once-a-month rate, it is necessary to reduce flow times without compromising safety or the depth of management oversight needed to implement effective program management. One of the ways to accomplish a greater number of preflight reviews within the available resources is through video or telephone conferencing. These approaches save travel time, thereby increasing the time Headquarters and Center managers can spend on other aspects of their job.

Over the last year, the Panel has audited many of the Space Shuttle Program reviews at the Kennedy Space Center. The overall impression of the Panel was that the meetings were productive and produced a positive result relative to management awareness of the status of critical systems. This awareness resulted in more effective and efficient risk management because decision-makers had a more complete and first-hand understanding of problems and remedial actions.

Unfortunately, video and telephone conferences are not a total replacement for face-to-face meetings. They are nonpersonal and can be compromised by poor transmission quality and other technical difficulties. Also, a manager participating in a video or telephone conference from his/her home base may be more prone to interruptions and distractions than would occur at the meeting site. Further, video and telephone conferences preclude off-to-the-side discussions that are necessary for a clear understanding of issues being discussed.

It seems clear that a shift from face-to-face meetings to video and telephone conferencing will be necessary to accommodate the manifested Space Shuttle flight rates. This shift should pose little difficulty for some of the relatively short-duration reviews conducted early in each launch flow. As the time to make a final decision to launch approaches, however, increased benefits are derived from face-to-face meetings. There simply is no substitute for trained professionals working through problem explanations and solutions in the same room. Therefore, it would appear appropriate to continue to hold meetings at the Kennedy Space

Center for the flight readiness, Launch-2 day, and Launch-1 day reviews.

It might be worthwhile to have specific time allocated after each formal meeting at the Kennedy Space Center for discussion of issues associated with subsequent launches that are being worked. This would permit managers to interchange information on a face-to-face basis without any additional travel costs or days away from their offices. In addition, as the launch rate approaches one per month, it may be possible to manage the schedule of reviews to accomplish more than one review on each trip to the Kennedy Space Center. This would preserve many of the face-to-face interactions while still reducing the travel demands on managers.

TECHNICAL ISSUES (Ref: Findings #4, #5, and #6)

The closest analog to the problems of human performance and capacity during space missions deals with aircraft pilot workload (both underload and overload). The applicable model of human operations resembles a system dependent on queuing. The major issue concerns the ability of the operator (astronaut or Space Station crew member) to successfully handle--in terms of safety and mission achievement--an additional task or input that can arise at any time. This issue raises the following questions:

- What will be the impact of planned work timelines, extended periods of zero-g, and long extravehicular activity work efforts on the crew's ability to correctly recognize, evaluate, and cope with unforeseen events in a timely manner?
- What measures can be used to predict performance and capacity decrements *before* detrimental impact to operations or safety?
- Are performance-based criteria being considered as part of the profiles for various extended duration missions?
- Is there a program to research performance and capacity problems, and develop appropriate predictive methods?

Performance and capacity issues are potentially quite dangerous to future crews because there are no available measures to indicate when spare capacity has been exhausted. The potential problem actually may 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 indicators of difficulty, there is no way to estimate if contingencies can be handled.

As part of this issue, the Space Shuttle's automatic landing capability should be qualified so that it will be available if the research indicates a problem with manual landings after extended stays in orbit.

The Panel acknowledges the work NASA has done to improve the safety of the Space Shuttle. However, the Space Shuttle is still very much a research and development activity with significant chances for accidents and failures. Possible consequences of a Space Shuttle accident or failure could result, for example, in one of the following scenarios:

a. ***Orbital Decay*** - The Space Station will require occasional reboosting to maintain orbit. During assembly, the Space Station Freedom orbit will be allowed to decay while materials are launched into orbit for its assembly operation. In the event that a Space Shuttle problem prevents the reboost operation, if left unattended the partially assembled station could reenter Earth's atmosphere with possible serious consequences.

b. ***Stranded Astronauts*** - Even if a vehicle for crew emergency return is planned, there is a good chance the astronauts could be caught in space before the vehicle is ready for service and, thus, have no way to return to Earth.

c. *Loss of Critical Components* - If a Space Shuttle were lost or incapacitated for whatever reason, it is likely that the components of the Space Station it was carrying would be lost or unavailable for use. The time required for replacement could affect the success of the program.

The goals behind the Space Station Technical and Management Information System are laudable. However, NASA Centers continue to use their own systems with an intent to convert to the Technical and Management Information System when it is available. If this system does provide the tools it promises, this may be unhealthy because it will create an enormous data consistency problem. Conceivably, users might harbor doubts about the timeliness and integrity of the data in the system. Unfortunately, if the Technical and Management Information System is too late or does not provide the services promised, the center approach of "going it alone" becomes essential even though it does create future problems.

Centers that have not relied previously on a computerized technical information system plan to use the capability that will be provided by the Technical and Management Information System. Delays in providing this capability will have a significantly adverse effect on the ability of these Centers to conduct work for the Space Station.

B. SPACE SHUTTLE PROGRAM

ASSURED SHUTTLE AVAILABILITY PROGRAM

(Ref: Finding #7)

This program was initiated by both the Space Shuttle Program and the Safety, Reliability, Maintainability and Quality Assurance organization, with a number of objectives: improve safety and reliability; replace obsolete systems; meet and/or improve flight rate; reduce recurring costs; and improve performance and capability.

Discontinuing the use of the term "Shuttle Enhancements" with its connotation of optional adoption, in favor of the current "Assured Shuttle Availability," which is a more positive statement of program objectives, is endorsed by the Panel. The Panel believes that this program will continue to lower the risks and stabilize the elements of the Space Shuttle Program.

The Assured Shuttle Availability Program, when properly implemented, will be responsive to the Aerospace Safety Advisory Panel Chairman's testimony before the House Subcommittee on Space Science and Applications on September 28, 1989. This program also was supported by the Congressional Office of Technology Assessment in its August 1989 report, entitled "Round Trip to Orbit," which discusses alternatives to improve safety, reliability, and space operations.

In further support of the Panel's position on future risk reduction activities is the following statement made by Dr. H. Guyford Stever, Chairman, Panel on Redesign of the Space Shuttle Solid Rocket Booster; and Project Director, Dr. Myron F. Uman of the National Research Council staff:

"Risk Reduction through Product Improvement.........The Space Shuttle is a very complex flight system operating in a very hostile environment. It is not realistic to view its missions as risk-free. It is however, reasonable to expect that a higher level of confidence can be acquired as more flight experience is obtained.

"The confidence will only be gained from measured performance of the system (including data from quality control review and post flight inspection). Risk cannot be assessed without a data base, and confidence comes from large data bases, which cannot be provided from pre-flight tests alone. It is standard practice in the aeronautical industry to monitor flight performance (from components to systems to the vehicle) and to make modifications to improve the product when the data base indicates that safety margins are below design requirements or potential failure modes are not adequately treated in the design.

"The need for such practices is even more important in the Shuttle system because the safety margins are lower than in the aeronautical industry (due to considerations of weight), and the opportunity to develop a performance data base is orders of magnitude more limited. This message was dramatically conveyed by the Challenger accident and the conditions leading to it. The thorough redesign and verification effort since then reflect a new set of standards within NASA and the space industry. It is important that these standards be continued in the flight program, and that budgetary, manpower, and facilities policies be consistent with that objective.

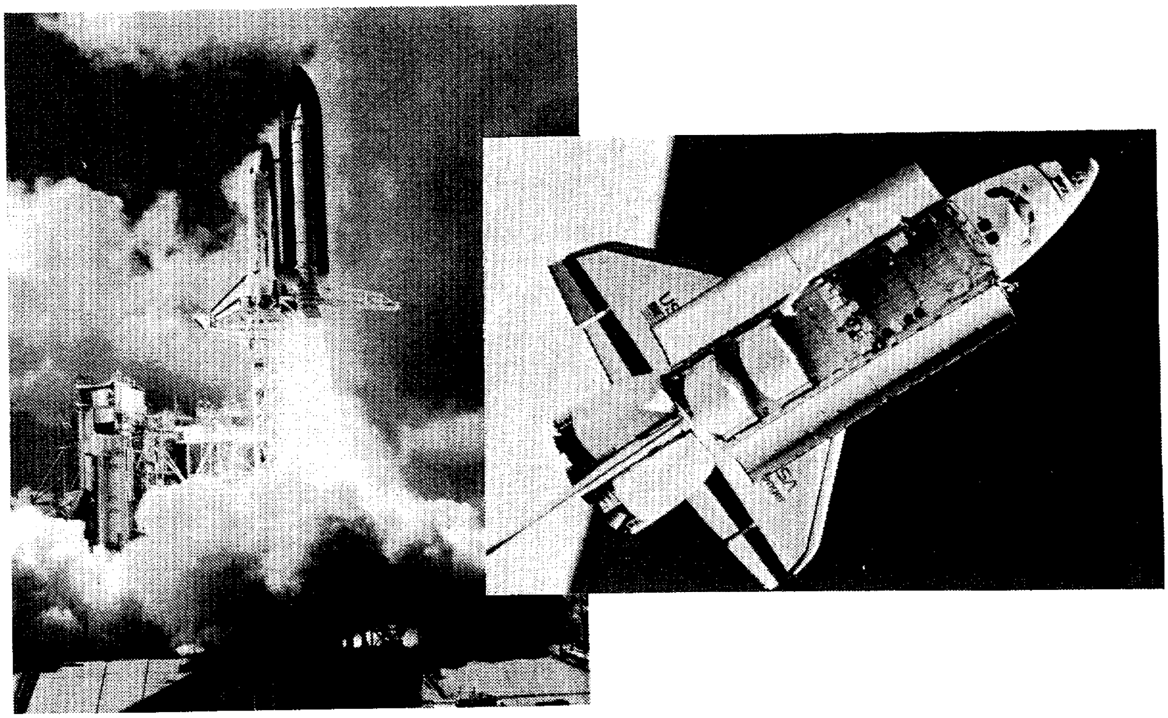
"Our panel's detailed reports to NASA contain a number of some specific recommendations for effective control and reduction of risk throughout the flight program.

"Conclusion. The reworking of the Space Shuttle, not only of the Solid Rocket Booster but of many other systems, subsystems and components, and, as well, of requirements, manufacturing and handling processes, etc., was a difficult and sometimes thankless task. Looking back, it was badly needed, not only for the field joint that failed but for many other items as well. Carried out in the blinding lights of a Presidential Commission, Congressional hearings, oversight committees, from both within and outside NASA, thorough professional society reviews, a disturbed and fascinated public, and a hyperactive media, it was remarkably well done, albeit with considerable grief. It did not have to happen. We hope that the national experience will forever remind engineers and users of technological systems, great and small, that it is much better to do it right the first time. But if design weaknesses affecting safety or reliability eventually become apparent in use, they must be understood and corrected."

SPACE SHUTTLE ELEMENTS

Orbiter (Ref: Findings #8 through #11)

The ASAP has monitored closely the status of the continuing evaluation and modifications of the structures of the Space Shuttle stack and the major elements comprising the stack. This includes elements such as the orbiter and the solid rocket boosters as well as the methodology employed to account for the day-of-launch wind conditions. NASA has completed a major reevaluation of the loads and structural capabilities of the Space Shuttle--referred to as the 6.0 loads analysis. The results of the analysis indicated that parts of the orbiter structure did not exhibit the 1.4 factor of safety when subjected to the Integrated Vehicle Baseline Configuration-3



(IVBC-3) environment. As a result, the trajectories of the orbiter had to be restricted, which reduced the probability of launch.

This is not a new situation. During the first 5 flights of the Space Shuttle, data from 10 strain gages installed in the orbiter wings indicated that the loads on the wings were greater than those predicted by the math model used at that time. To adjust the output of the math model so as to correlate with measured loads, a "collector load" was developed that, when added to the loads predicted by the existing math model, would yield loads like those measured in flight. The structural capability of the orbiter under these loads was designated Orbiter Capability Assessment-D (OCA-D). In effect, the orbiter structure was certified to a somewhat lower environment than that specified by the IVBC-3 description.

The structurally allowable flight conditions of the orbiter are frequently displayed graphically on plots of q-alpha (dynamic pressure times angle of attack) versus q-beta (dynamic pressure times angle of sideslip) as shown in Figures 4A and 4B. The contours plotted are the boundaries of allowable combinations of coordinates that will result in loads that will not violate the 1.4 factor of safety for structure. Typically, these plots are made for Mach numbers over the range from 1.05 to 1.25. It is over this range of flight speeds that maximum loads are experienced. The contours are frequently referred to as "squatcheloids." In Figures 4A and 4B, the outer contour represents the flight envelope that would be available were the structure capable of sustaining the loads resulting from the IVBC-3 environment. The dashed contour represents the allowable envelope under the OCA-D evaluation. The innermost

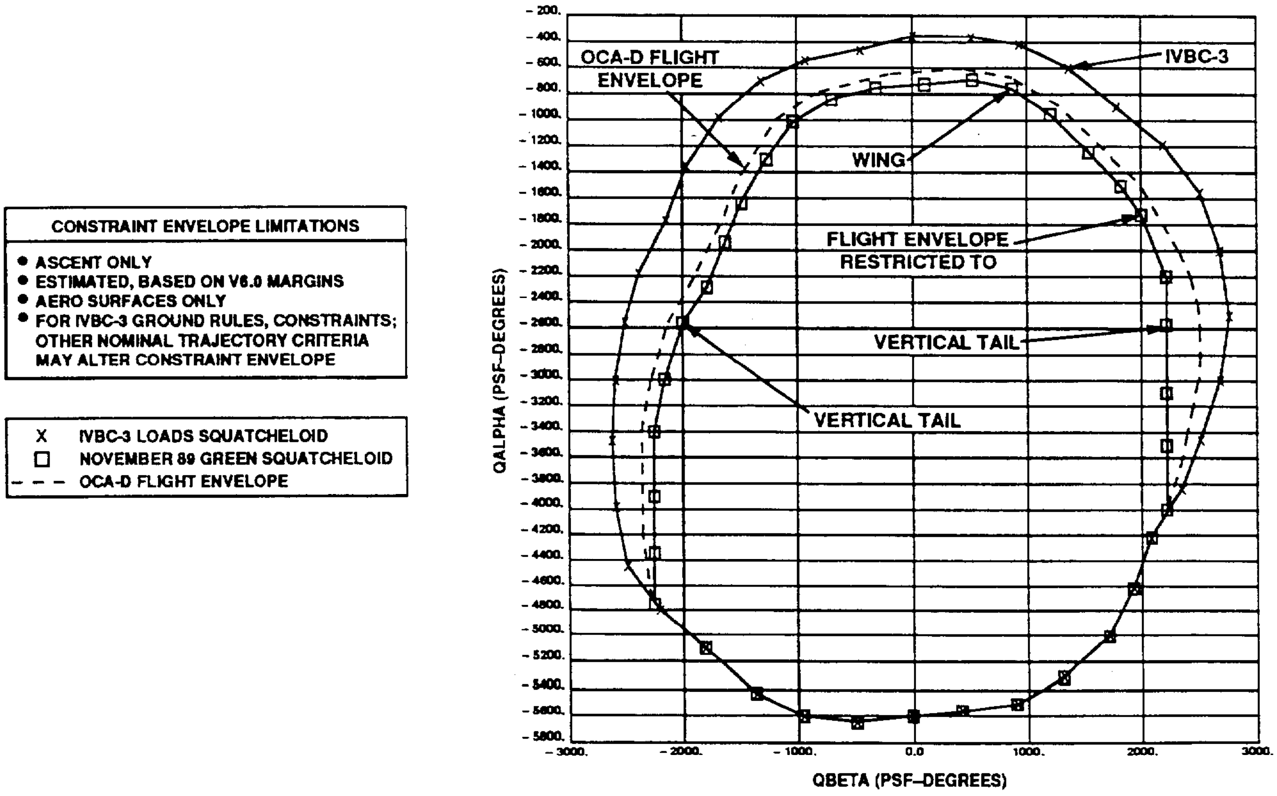


Figure 4A, MACH = 1.25
Restricted Green Squatcheloid and IVBC-3 Loads Squatcheloid

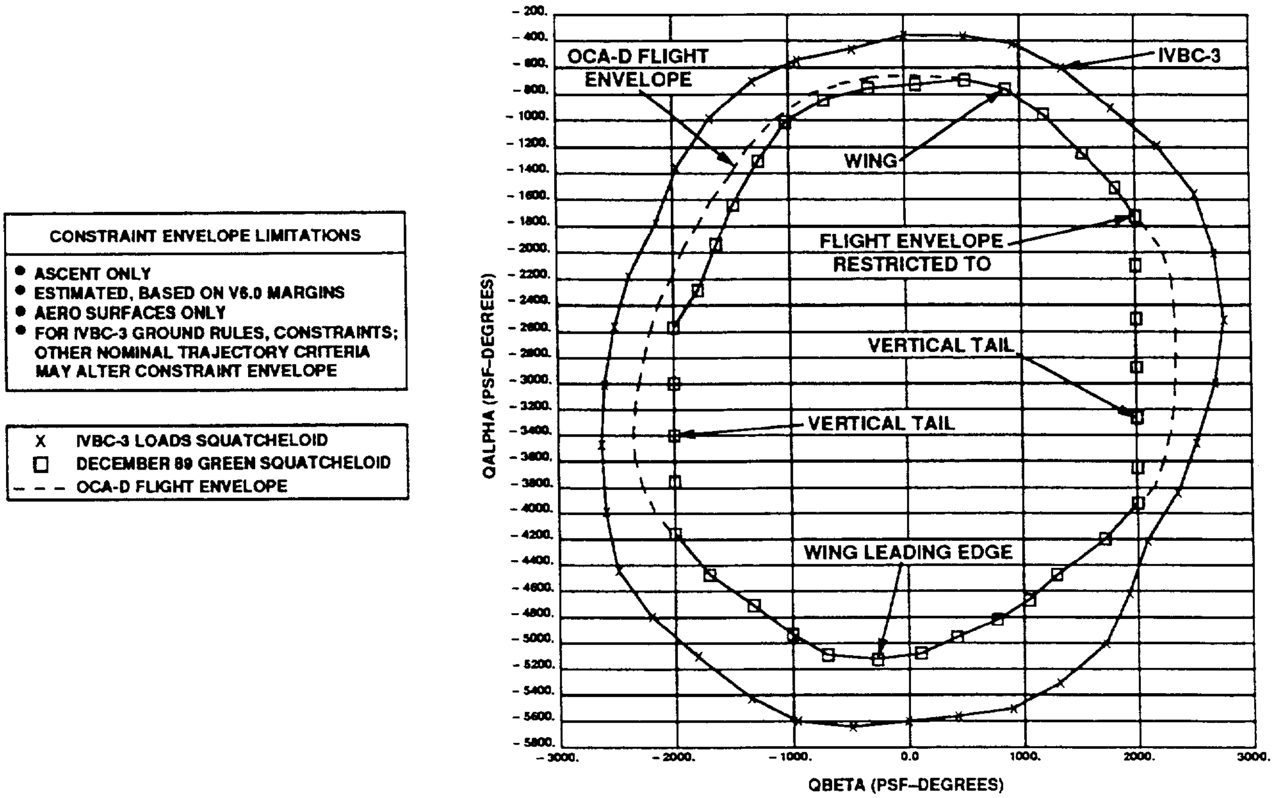


Figure 4B, MACH = 1.25
Restricted Green Squatcheloid and IVBC-3 Loads Squatcheloid

contour is the allowable envelope from the most recent (6.0) loads and stress the assessment. This latest assessment showed that there were five major elements that had negative structural margins (factors of safety less than 1.4). Hardware modifications already have been incorporated to permit flight within the inner "squatcheloid" (often referred to as "green squatcheloid") with a factor of safety of 1.4 or greater. Additional modifications designed to enlarge the allowable envelope are being reviewed for cost and schedule effects. These are indicated in Figure 5. Of particular significance are the modifications for the wing structure.

A structural element, the vertical tail, has caused significant narrowing of the allowable flight envelope. The effect is shown in Figures 4A and 4B. Since that figure was drawn, the external loads model for the vertical tail has been revised and recalculated. The revised calculation included a new aeroelastic model and data that yielded significantly reduced root bending moment on the tail. At the critical Mach number of 1.25, the moment decreased from 8.5 million in-lb to 6.7 million in-lb. The calculations employed the Automatic System Kinematic Analysis 6.0 loads model (referred to as the "6.0 loads"). The reduced moment will significantly expand the allowable flight envelope, especially in the sideslip dimension. The more than 20 percent reduction in the airloads on the vertical tail identified by this latest analysis, after years of design reviews and calculations of design loads, should be reexamined carefully and (more importantly) substantiated by flight test measurements. The preceding discussion pertains to loads produced by aerodynamic forces as indicated by the use of the q-alpha and q-beta parameters. There are other structural loads controlled by

NEXT FLIGHT	OV-102 (8)	OV-103 (9)	OV-104 (5)	OV-105 (1)
MID FUSELAGE				
FRAME STRUTS	(8)	C	C	(1)
HINGE FITTINGS	(8)	C	C	(1)
CARRY THROUGH STRUT	(8)	(9)	(5)	(1)
AFT FUSELAGE				
OMS DECK FRAME CAPS	(15)	(15)	(13)	(1)
THRUST STRUCTURE SHIMS	(8)	(9)	C	(1)
WING				
TRUSS TUBES	A	B	B	(1)
UPPER SKIN PANEL	A	B	B	(1)
SPAR WEB	A	B	B	NA
SPAR JOINT	A	B	B	(1)
OMS POD	C	(9)	C	(1)
WEB AND LONGERON LEFT	C	C	C	(1)
RIGHT				
TPS	(8)	NA	NA	NA

NUMBERS SHOWN ARE THE FLIGHT EFFECTIVITIES

A = TBD PENDING COMPLETION OF ANALYSIS
B = COST AND SCHEDULE UNDER REVIEW
C = COMPLETE
NA = NOT APPLICABLE

Figure 5, Structural Modifications

compartment pressurization or, more correctly, pressure differentials that are not aerodynamic in origin. An example of a structure so loaded is the Orbital Maneuvering System (OMS) pod deck frame. Elaborate calculations have to be made before each flight to ensure that the pressure differentials across the structure will not exceed allowables. It has been recommended that installing a set of vent valves would limit pressure differentials, thereby minimizing the problem and opening the allowable envelope. Structural modifications have been approved to mitigate the problem but installation is scheduled for October 1990 for Orbiter Vehicle (OV)-103, April 1992 for OV-104 and December 1992 for OV-102, even though the engineering is complete and the mod kits are available.

In past reports, the Panel has recommended that the wings of OV-102 (which are heavily instrumented with strain gages and pressure sensors for flight loads determination) should be subjected to loads calibration prior to use of the instruments. The flight for the experimental determination of actual loads is now scheduled for 1991. The loads thus determined will be compared with analytical predictions. Present NASA planning is for the strain gages to be checked electrically only before flight data are acquired and to load-calibrate them after the fact. A credible experimental loads determination can be made only if an end-to-end (load to instrument output) calibration is conducted **prior to flight**. The Panel reiterates its stated position: calibrate the OV-102 instruments before flight.

Day of Launch Loads Determination

The flight envelope represented by the squatcheloids are based on winds aloft profiles that have been determined statistically ("statistical winds" that vary with season). On the day of flight, the existing winds must be considered and their effect on the loads determined. This is done by a designated engineering team (Launch Support and Evaluation Assessment Team). The team provides a "go" or "no-go" to the Deputy Director, Space Shuttle Operations. The winds aloft are determined from radar tracking of special balloons called "Jimspheres" that are released at specified intervals during the launch countdown. The data are fed into computers at several sites and the loads at critical locations (load indicators) are calculated. These calculations include not only the measured winds but also impose a 9-meter-per-second discrete gust on the vehicle. Also, a "persistence factor" is added to account for the temporal variability of the measured winds. This factor and other trajectory dispersions caused by vehicle system dispersions are determined from statistical analysis of wind and systems data.

Because the last winds data available prior to lift-off are at least an hour old by T-0, it would be advantageous (in terms of probability of launch) to have wind data obtained closer to launch. Newer methods of wind determination such as ground and airborne doppler radar sounding techniques offer the potential for wind measurements within minutes of lift-off. Data bases that are being developed for the new measurement techniques may help to reduce the uncertainties in day-of-launch loads calculations.

Orbiter Windows (Ref: Finding #12)

Recent analysis of the results of postflight inspections of orbiter windows indicates that the frequency of damage to the windows is greater than had been believed from previous reviews. The data show that 25 windows had been pitted, 11 of which were damaged severely enough to warrant removal. The source of the damage is difficult to determine; however, the consequences are increased turnaround time and, possibly, concern about the structural integrity of the windows. Astronaut John W. Young of Johnson Space Center has made suggestions concerning this issue that warrant serious study and consideration:

- Use thicker or improved glass. This could be done as part of the Assured Shuttle Availability Program.
- Select vehicle on-orbit attitude affording greatest protection from orbital debris, subject to thermal control constraints and mission requirements.
- Plan and brief flight crews for entry angle of attacks selected to afford maximum protection from entry heating for windows that may have sustained serious damage. Train the crews for such contingency entries.

Space Shuttle Computers (Ref: Findings #13 and #14)

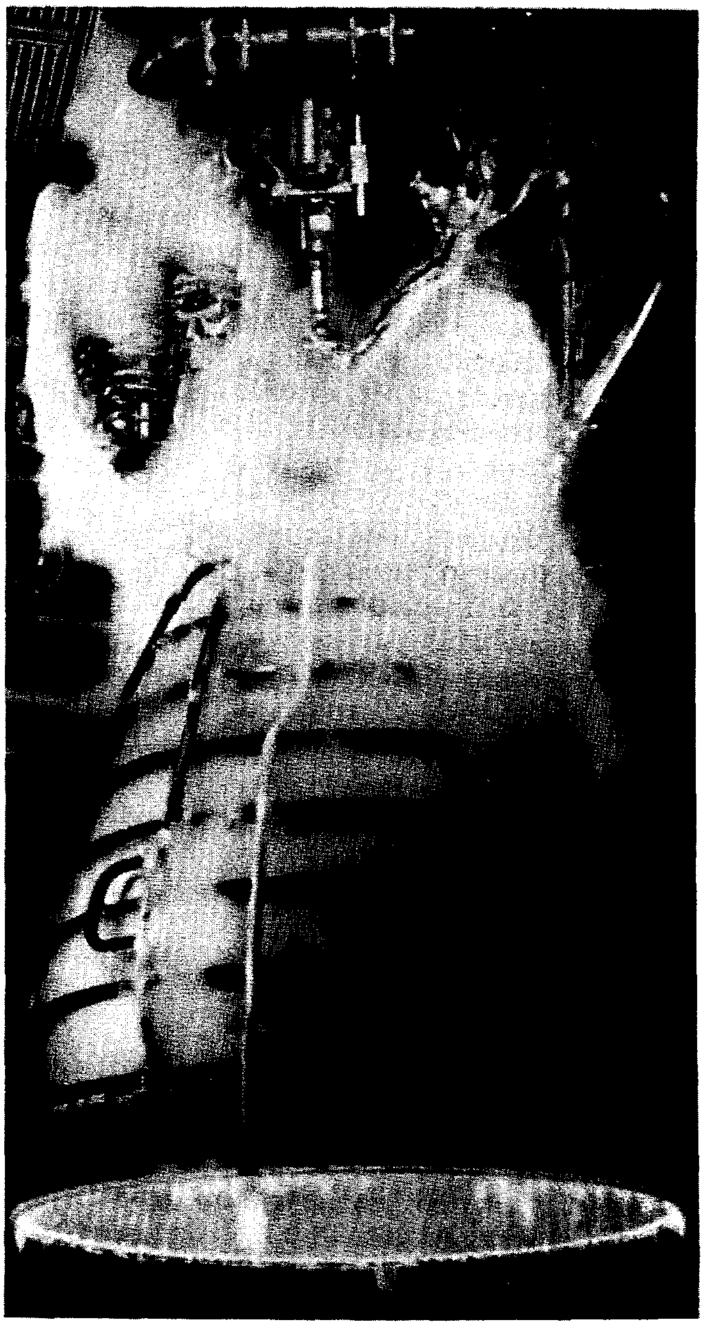
The Space Shuttle is expected to continue in use for another 20 to 30 years. This operation will depend heavily on a variety of computer systems. For the past 20 years or more, new generations of computers and computer capabilities have been introduced about every 2 years. This pattern is expected to prevail for the foreseeable future. An unfortunate consequence of this situation is that spare parts become difficult to obtain; and when a new product is released, most software development for the older processors ceases. Thus, it will most assuredly be necessary to upgrade several different computer systems within the Space Transportation System (orbiter, main engine, and Kennedy Space Center launch processing at least) several times within its lifetime. To date, each organization responsible for a subsystem acts as an independent entity in planning its computer upgrades. Each manages to install new computer systems that are approximately a decade out of date by the time they become operational. It would benefit NASA to develop an overall strategy for upgrading its computer systems and apply that strategy to all of its major programs requiring upgrades.

The first flight versions of the new general purpose computer were delivered in February 1988. The transition to using these versions in actual flights has been delayed by several problems detected during the testing of the flight units that had not appeared in the prototype units. The errors have resulted in at least three design changes in the new general purpose computer hardware.

Space Shuttle Main Engine
(Ref: Finding #15)

In last year's report, the Panel listed safety enhancements that would reduce the risks of Space Shuttle flight. For the Space Shuttle Main Engines, the list included: high pressure oxidizer turbopump, two-duct hot gas manifold, large-throat main combustion chamber, single-crystal turbine blades, and weld redesign. Progress has been made in all of these areas, although at significantly differing rates. The status of the work on these subjects is discussed below following some general comments.

The Space Shuttle Main Engines have continued to perform satisfactorily in flight. The fixes described in last year's report for the turbine blade cracking problems continue to be effective. The 4,000 Hz resonance problem has been avoided by appropriate screening in test. A permanent fix has been devised for the liquid oxygen inlet splitter and has been tested with satisfactory results. The weld assessment program activity has continued during this year. Changes to weld designs are being incorporated as are improved inspection techniques. The additional work required is being accomplished in accordance with a well-organized, prioritized plan. Rocketdyne is to be



commended for its achievements to date and should be encouraged to continue these effective, safety-enhancing activities.

Problems remain with the engine turbomachinery. The more serious issues concern bearing life in the high pressure oxidizer turbopump and the high pressure fuel turbopump. The oxidizer pump has the more serious difficulty. In both instances, the situation is being addressed in a two-step approach. The first step is to improve inspection/diagnostic techniques, which will enable a more objective evaluation of the condition of the bearings. This will permit safe reuse of bearings and reduce the need for removal of turbomachines for teardown and bearing replacement. The ability to reuse bearings will mitigate the operational impact of turbopump removal as well as the strain on engine spares.

The second step is to incorporate design changes in the bearings and their installation. These changes are intended to relieve the loading and dynamic interactions within the turbomachines, and increase the load-bearing capacity of the bearings so as to increase both margins of safety and life. The nature of these changes for the turbomachinery are described in the following paragraphs.

High Pressure Oxidizer Turbopump

At present, pump-end bearings are limited to one flight. The turbine-end bearings can be used for up to three flights if they pass the shaft-travel test after each use. The limited life of the pump-end bearing necessitates removing the turbomachine after each flight and replacing the pump-end bearings as a precaution regardless of whether excessive wear exists. An inflight bearing wear monitor is being developed for the pump-end bearings. It has been determined from ground tests, that unacceptable bearing wear is signaled by the appearance of cage frequency harmonics in the vibration spectrum of the turbopump. Strain gages mounted on the pump housing can detect these vibrations, and test correlations show that if they are absent the bearings may be reused safely. It is anticipated that with this health monitoring technique, the pump-end bearings may be used as many times as the turbine-end bearings. The instrument is scheduled to be flown in the spring of 1990.

To ensure the confidence in the shaft-travel test used for the turbine-end bearings, a special tool has been developed with which to perform the test. The tool provides greater accuracy and repeatability, and eliminates operator influence on test results. A prototype tool has been built and demonstrated on a pump. Designated the micro shaft-travel test tool, this device can be used while the turbopump is on the engine.

The above health-monitoring techniques are interim steps to enhance the safe-use life of the high pressure oxidizer turbopump. A longer range program to improve the machine is being conducted. The objectives of the design changes are to: reduce bearing loads, improve load sharing among the bearings, reduce friction in the bearings proper, and improve cooling. The approaches being taken are indicated in Figure 6. Basically, load management is being addressed by mounting the pump-end bearings inside a mono-ball so as to permit steady-state and dynamic loads to be shared more equally among the bearing sets and within the sets. The thin inducer and 15-vane inlet will alleviate dynamic loads and reduce loads caused by cavitation at the pump inlet. Bearing friction is reduced by

WEAR DRIVERS	DESIGN APPROACH	
	PUMP END	TURBINE END
LOAD MANAGEMENT	MONOBALL INCREASED PRELOAD	SOFT SPRING
LOADS	THIN INDUCER/15 VANE INLET	THIN INDUCER/15 VANE INLET
LUBRICATION	FEP CAGE	FEP CAGE
COOLING	BACKPRESSURE SEAL	INCREASED FLOW
WEAR RESIST	ION IMPLANTATION	ION IMPLANTATION ELONGATED CAGE POCKETS

Figure 6, HPOTP Bearing Enhancement Plans

coating the cages with fluorinated ethylene propylene. Cooling of the bearings is improved by changing seal clearances to reduce coolant leakage at the pump-end and providing more coolant flow at the turbine-end.

To improve wear-resistance of the bearings, ion implantation is being employed to change the ball material surface properties. The individual changes have been tested with good results and a pump with all the modifications incorporated is in test. Certification testing should be completed by mid-1990.

High Pressure Fuel Turbopump

With the turbine blade cracking problem brought under control by the changes described in last year's report, the bearings and seals have become the governing life-limiting components of the high pressure fuel turbopump. The bearings are its most life-limited part. The bearing problem manifests itself by cage cracking. The solution is to provide increased width and thickness to the cage to increase its load-bearing capacity and to coat the cage with fluorinated ethylene propylene as in the high pressure oxidizer pump. Early test results on three units are very encouraging. If results continue to be good, certification testing should be completed by mid-1990.

The seal issues are being addressed by installation and material changes as well as configuration changes to existing seals. These changes enhance seal damping in the shaft seals (which reduces dynamic loads), provide wear inserts in the impeller bores so that wear does not affect metal parts, and improve the first-stage turbine tip seal capacity by grooving to improve the load distribution. Most of these changes have been in test with good results.

Gaseous Oxygen Heat Exchanger

This component always has been a safety concern because of the potential consequences of a leak. The main source of concern has centered on the welds in a bifurcated joint that is exposed to conditions within the hot gas manifold. very stringent material and fabrication restrictions have been implemented to control the situation, but the concern is ever present. To eliminate the problem, a dual approach has been taken. The first is to produce a single-tube heat exchanger with increased structural capacity. This design eliminates the welds located within the hot gas manifold. The second is to provide an external heat exchanger that would eliminate the potential for interpropellant leakage.

Both approaches have produced good results. For the single tube approach, full length tubes of 0.032 wall thickness (vice 0.0125 in the existing design) have been produced. All interpropellant welds have been eliminated--in addition to two other welds--and seven welds have been redesigned to improve manufacturability and inspectability. This approach has the advantage of being compatible with the remainder of the existing system and would require only minor changes in installation hardware.

The external heat exchanger has successfully completed many component hot-fire tests off the engine. It is currently undergoing redesign to improve structural margins and inspectability over the original design. Present plans are to certify and incorporate the single-tube heat exchanger with the two-duct powerhead.

Phase II+ Powerhead

This modification, formerly referred to as the two-duct hot gas manifold, has successfully completed development tests. This configuration has significantly reduced the transverse pressure differentials across the high pressure fuel turbopump, which reduces the side loads; and provides a much more uniform velocity distribution in the gas flows, which reduces the pressure losses in the system. The consequences of these improvements include a decrease of approximately 40 degrees Fahrenheit in turbine outlet temperatures for both fuel and oxidizer turbopumps, and a more than 200 rpm decrease in high pressure fuel turbopump operating speed. These effects increase the operating margins of the turbopumps. The current proposal is to complete certification and introduce this modification in 1993.

Large-throat Main Combustion Chamber

This modification to the Space Shuttle Main Engines has continued in test as part of a technology program, rather than as a formal part of the SSME safety enhancement activity. To date, test results have shown that this change significantly reduces turbine temperatures, with temperatures at 109 percent thrust being less than the current configuration at 100 percent thrust. This significantly increases turbine component life while increasing operating margin. The system pressures also are reduced; operation at 109 percent is comparable to the current engine at 104 percent. At the same time, the turbopump shaft speeds and torques are reduced, extending turbine blade and bearing life. The combustion stability of the large-throat main combustion chamber has been demonstrated by bomb tests; no instabilities were encountered throughout the start cycle and into steady-state operation.

The only concern is the change in operating point of the liquid oxygen pump with the new main combustion chamber at minimum net positive suction pressure. This can be overcome with the thin blade inducer and 15-vane inlet that are already being incorporated in the high pressure oxidizer pump as part of the bearing life increase program discussed above.

The only remaining issue is the possible reduction in specific impulse. Tests to date have not indicated such an effect; however, the test-stand instrumentation used was not of sufficient precision to reach a firm conclusion. The principal suspect for a reduction in specific impulse, a shock downstream of the throat, was not detected. Improved instrumentation is being installed and results should be available in early 1990.

Current considerations are to defer incorporation of this safety-enhancing modification until other changes being contemplated can be packaged with the main combustion chamber as a block change. If the large-throat main combustion chamber were to be removed from its "technology" status and incorporated in the Space Shuttle Main Engine safety-enhancement program, it could be expedited. Certification and implementation could be effected in the same timeframe as the Phase II+ powerhead. Considering the substantial margin increases that would be achieved, this would be a very worthwhile way to enhance the safety and reliability of the main engines.

Single-Crystal Turbine Blades

One of the ways to increase the strength, fatigue resistance, and life of the turbine blades is to change the materials from directionally solidified MAR-M-246 to the single-crystal 1480 material. A development program to do this has been in effect for many years. Bench testing of the single-crystal material at room temperature indicates that it has from 4 to 25 times the fatigue life of the present material. A large number of blades of the 1480 material were to have been delivered for testing prior to the end of 1989. There is still no firm schedule for these tests.

The principal concerns for the new material are the crack growth rate and other issues of material characterization. In a parallel activity, an improved version of the MAR-M-246 material is being investigated. This version is produced by a "high-gradient" casting technique that yields more uniform material with fewer and smaller carbide particles more uniformly distributed. Such properties should enhance both the low-cycle and high-cycle fatigue properties of the blades.

Alternate Turbopump Development Program

In a parallel approach to improve the reliability and life of the main engine turbomachinery, an alternate design and development program was undertaken with Pratt & Whitney as the contractor. The basic requirements for the machinery were similar to the original Rocketdyne performance specifications. Pratt & Whitney has made extensive use of the lessons learned in the more than 15 years of development and operational experience with the current turbomachines, and from a design viewpoint, should have avoided the problems encountered by the Rocketdyne design. For example, complex welds have been avoided largely by the use of precision castings, parts counts have been reduced considerably, and hydrodynamic designs have been selected so that they can accommodate the actual operating point(s) of the integrated engine. Material selection has been guided by the increased knowledge of the mechanisms of hydrogen embrittlement gained over the past 15 years.

Extensive detail component testing in specially designed tests rigs are an important part of the development program. The ability to test individual turbopumps in a facility rather than on an all-up engine is very important. Such a facility permits extensive instrumentation with which to map out turbopump performance over an entire spectrum of operating conditions so that potential marginalities or instabilities can be identified and corrected early in the development process.

The program is nearing the individual turbopump test phase. As is usual development problems have been encountered that will impact the schedule. Specifically, more development is required to mature the casting of structural elements. Experience dictates a redesign of the high pressure fuel turbopump housing to enhance manufacturability. Also, stress corrosion cracking has been experienced in some bearing inner races during rig testing and corrective action is being pursued. Overall, the program is progressing well. The critical hurdles will be encountered during the individual turbopump tests.

It is commonly agreed that the Space Shuttle Main Engines constitute the most safety-critical system in the Space Shuttle. Like other Space Shuttle elements, the main engines may be considered as still in the research and development phase. As indicated above, progress has been made in all of the areas deemed to need safety enhancement; although at differing and sometimes frustratingly slow rates. It is recognized that each safety-enhancing modification has its own complexity and scope. Some modifications involve time-consuming manufacturing lead times and development tests on full-scale engines to validate. Yet, it is believed that progress could be accelerated by a more aggressive program. Also, despite the progress made on the alternate turbopumps, it would be imprudent to slow down the work on the existing turbomachines in anticipation of continued success in the development of the new turbopumps.

Redesigned Solid Rocket Motor and Solid Rocket Booster

(Ref: Findings #16, #17 and #18)

Booster Aft Skirt

During the test of Static Test Article-3 (STA-3) at the Marshall Space Flight Center, a weld on the booster aft skirt failed at 128 percent of limit load. The skirt continued to sustain added loading without collapse until 141 percent of limit load at which point the test was terminated. Waivers permitting the use of the aft skirt with a 1.28 factor of safety have been processed for each flight.

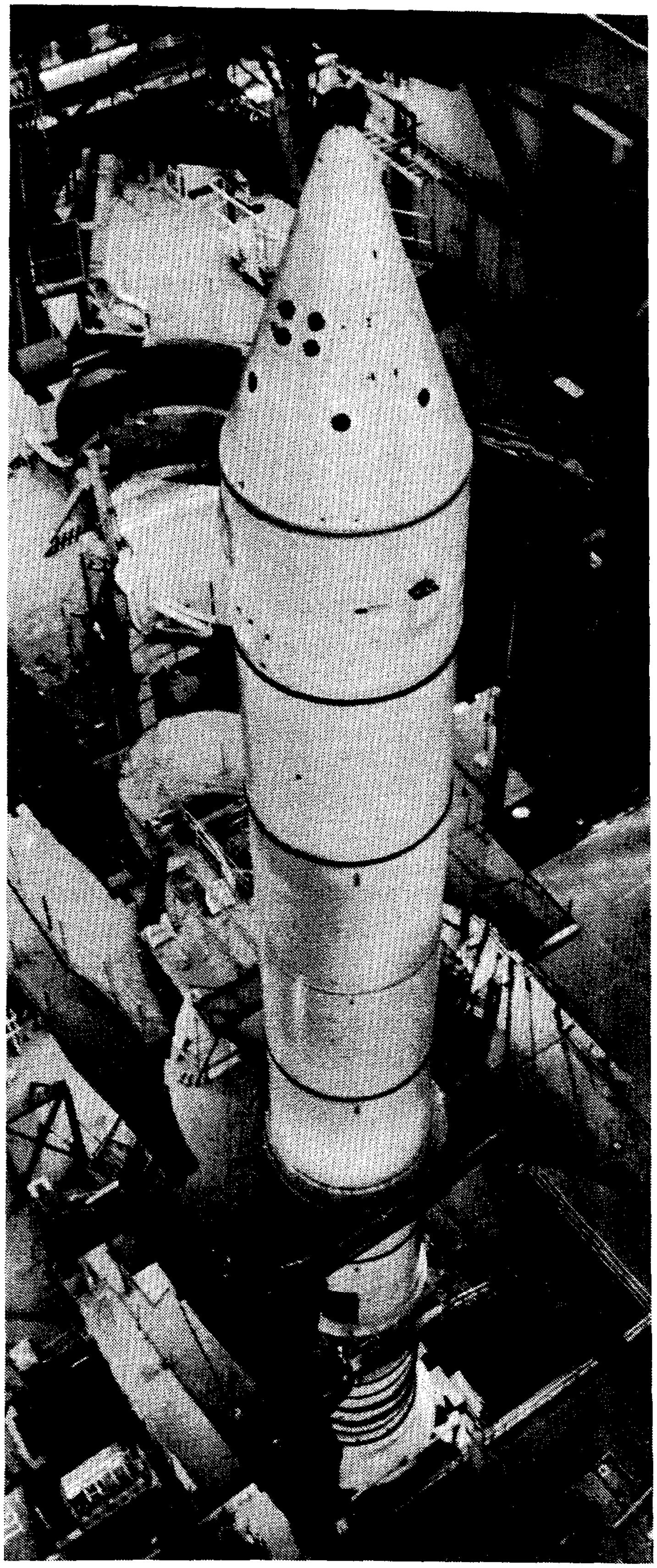
The aft skirt is subject to its maximum loading prior to lift-off during the deflection of the stack ("twang") caused by the start of the three main engines. Main engine thrust buildup and vehicle weight constitute approximately 92 percent of the design load applied to the aft skirt. Therefore, the probability of violating the 1.28 factor of safety is quite remote. Strain gage measurements have been taken on the aft skirt and hold-down posts of the launch pad to better define the character of the loads on the aft skirt. Complicating the attempt to better understand the situation are difficulties in defining the radial load reactions at the hold-down posts and also the allowable stresses of the skirt weld.

In an attempt to reduce the loads imparted to the skirt, the installation of the spherical bearings on the hold-down posts have been biased to effect a more equal distribution of the loads. This appears to have been effective. However, biasing requires a delicate adjustment of the bearing installation, which if done improperly, could increase the loads at the hold-down posts. Because of these uncertainties, it would be prudent to improve the aft skirt structure through changes to things like configuration, assembly, and/or materials. Such changes would eliminate the need for "routine" waivers (an oxymoron). It also would eliminate the continuing effort to try to understand the problem.

At a minimum, a detailed analysis of STA-3 data should be conducted to provide an understanding of the load redistribution that permitted the structure to sustain 141 percent of limit load after weld failure. This analysis should include the dynamic effects of the shock at weld failure on the booster systems attached to the skirt such as the hydraulics and thrust vector control components. Positive results from such an analysis would provide added confidence in the aft skirt.

Redesigned Solid Rocket Motor Field Joints

The redesigned field joints contain joint heaters and complex joint environmental protection systems. These systems, which are subject to malfunctions, significantly increase the time needed to mate motor segments and prepare the solid rocket booster for checkout. In addition, the systems are a source of lift-off debris that may damage orbiter thermal protection tiles. The need for heaters and the accompanying protection system arises from the decrease in elasticity of the O-ring seals that occurs in decreasing temperature, which reduces the ability of the seals to "track" the relative motion of the opposing joint surfaces during motor ignition.



During the joint redesign effort, a major test program was conducted to find a better low-temperature O-ring material. In addition to having good elasticity at lower temperatures, the material had to be compatible with the HD-2 grease used in the joint area to protect the steel case from corrosion from exposure to salt water. No material was found that was better than the fluoroelastomer used in the original design. Because of the concern about the tracking ability of the O-ring material, it was specified in the redesign that the O-ring had to be capable of tracking the gap opening at twice the maximum rate that would be experienced by the joint. This made finding an acceptable material even more difficult. Since that decision was made, tests on full-scale motors and postflight inspections of motor segments have shown that the new J-seal and capture feature prevent access of hot gases to the primary O-ring. Given these test findings as well as the difficulties of the joint heaters and protection systems, it appears worthwhile to continue a search for an O-ring material that would have satisfactory low temperature elasticity. At the same time, based on the performance of the J-seal, the requirement for a tracking factor of safety of 2.0 should be reevaluated with a view towards reducing it to 1.4.

Case-to-Igniter and Case-to-Nozzle Joints

The igniter and nozzle joints continue to require and receive much attention to assure that there will be no leakage of hot gases through the joint. Procedures for assembling these joints are under continual review. A particular concern for the case-to-igniter joint is that of putty extruding into the gasket/seal area, compromising the seal capability. This concern was heightened by the findings from the postflight inspection of the boosters for STS-34, resulting in more stringent procedures for assembly and added inspections for STS-34. Another concern is that of controlling irregularities at mating surfaces, which if excessive, would affect sealing effectiveness. In the case-to-nozzle joint, the concern regarding the application of the sealant material focuses on the generation of blow-holes (gas passages) during assembly. To date, no evidence of serious problems has been observed. But this depends on scrupulous attention to all the details of the assembly procedures. New designs exist that could eliminate these concerns, and others, for these joints. In fact, the designs have been proposed for the advanced solid rocket motor program. Serious consideration should be given to the development and implementation of these new designs for the redesigned solid rocket motor.

Other Considerations

There are a number of areas that require continuing attention. Among these are flight-support motor firings and the life extension program. At present, the redesigned solid rocket motor program conducts one full-scale motor firing a year. The purpose of this firing is to verify that the propellant mixing, casting, and motor assembly processes remain under control and produce motors that perform to specifications. In an effort to maximize the return from these firings, some development items are piggy-backed on the firing if they do not compromise the basic test objectives.

The hardware life extension program is required because many hardware items in the inventory are approaching their originally specified life. For example, static hardware in general was originally required to have a 10-year storage life. Many of these hardware items currently are scheduled for reuse even though they exceed the 10-year storage life. Similarly, dynamic hardware (such as auxiliary power units) were assigned service life limits based on qualification test results and analyses that were prescribed in terms of the number of mission cycles allowed. How much additional life will be allowed must be determined from thorough examination and evaluation of data and hardware as well as possible sacrificial tests of hardware to verify analytical results. The ASAP plans to monitor this activity.

Advanced Solid Rocket Motor

(Ref: Finding #19)

The advanced solid rocket motor program is in its early stages with the manufacturing facility and motor being designed concurrently. The automated/robotic manufacturing facility being designed represents a major advancement in the state-of-the-art in solid motor manufacture. This large a step in technology has attendant problems for both hardware and software that must be recognized and taken into account at the start of the design process. Even though some of the techniques may have been employed in other industries, their experiences testify to the complexity of automating manufacturing techniques, especially in the development of software. To these difficulties must be added the effects of the hazards of handling dangerous solid propellants. Because any motor design is an iterative process, the interaction of facility and motor design must be carefully controlled to avoid potential safety problems.

The advanced solid rocket motor program involves more than just the design and manufacture of a new large solid propellant motor. It must also integrate the new motor with the Space Shuttle system in which it will operate. For example, the increased diameter and weight of the motor will change both its structural and structural dynamic characteristics. This will require changes to the external tank attach ring, especially if the rate gyros are to be relocated to the orbiter as is currently planned. The Marshall Space Flight Center is developing both structural and structural dynamic math models of the advanced solid rocket motor for Rockwell to use to determine the design requirements for the external tank attach ring stiffness. Preliminary studies made in 1987 concluded that the advanced solid rocket motor loads would not be much different than those of the redesigned solid rocket motor so that the aft skirt would still be usable at the currently acceptable factor of safety of 1.28. The advanced solid rocket motor with its greater propellant load will weigh more than the redesigned solid rocket motor, however, and will lower the factor of safety. These and similar factors must be taken into account before the advanced solid rocket motor design can be settled.

The proposed advanced solid rocket motor design is responsive to many of the guidelines for a new motor design stated by the National Research Council Panel on the Technical Evaluation of NASA's Redesign of the Space Shuttle Solid Rocket Booster: use of an inherently tolerant design; detailed understanding of how the design works; a full spectrum of tests; performance testing of seals; validation of analytical computations; control of processes and materials; risk reduction through product improvement.

However, there are several areas in the advanced solid rocket motor design that require special attention:

- The longer forward segment increases the hazard associated with mandrel removal.

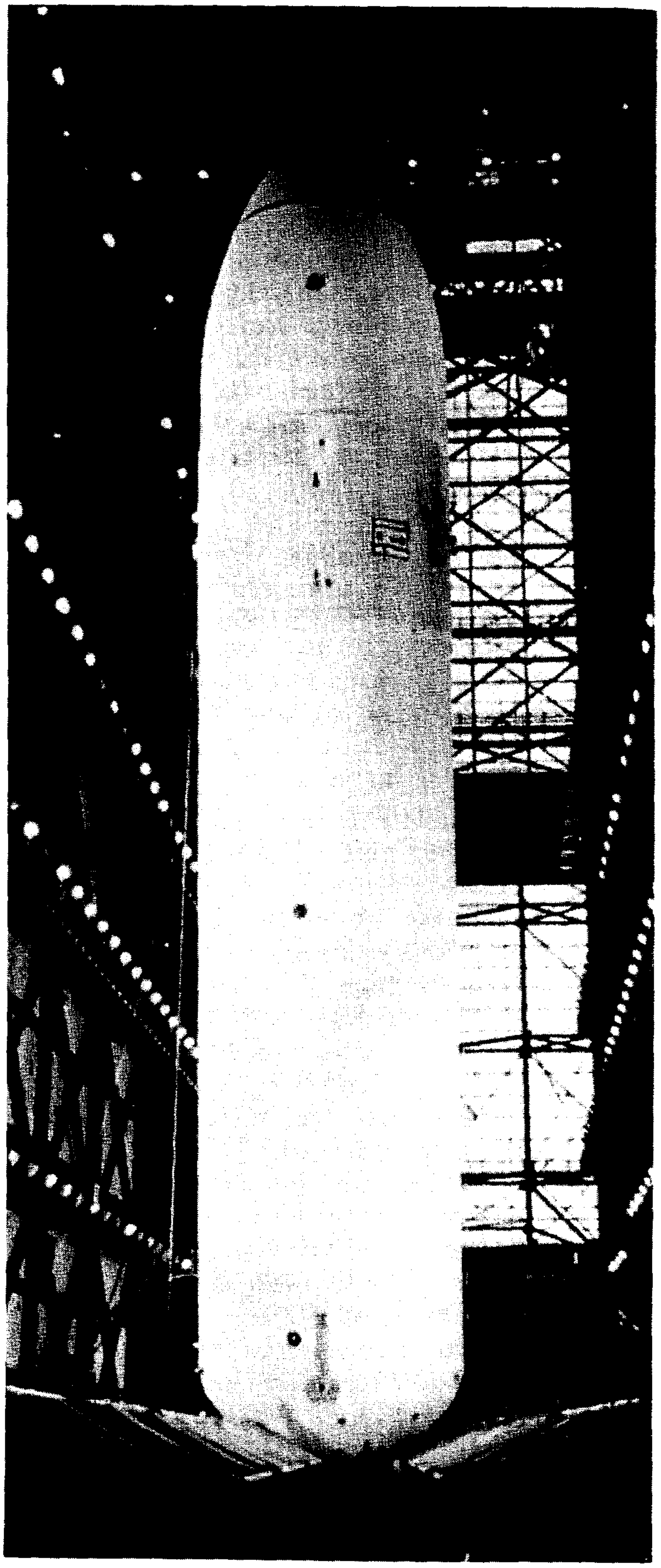
- The change in propellant composition by increasing the aluminum content from 16 percent to 19 percent in the hydroxyl-terminated polybutadiene propellant could increase the amount of slag deposited in the aft end of the motor.

- Welding of the maraging steel (HP 9-430) of the large diameter case is difficult and can produce voids and cracks in the weldment.
- The continuous propellant mix process with its long piping lengths may prove to be less reliable than the batch process.
- There will continue to be a single source for the acquisition of the large ring forgings needed for the design.

These and other aspects of the design will be monitored in the coming year.

External Tank (Ref: Finding #20)

The external tank has operated very well during the past 18 months. The number of issues raised as a result of flight and ground checkout anomalies has been negligible. Most anomalies involve instruments/sensors or external insulation, all of which are considered minor. The external tank tumble valve is used to assure a proper footprint for those pieces of the tank not burned up on entry. However, data returned from a number of flights indicate that this tumble valve activity is not required and only presents another complexity and cost. As a result, the tumble valve appears to be an unnecessary appendage.



Launch, Landing, Mission Operations (Ref: Finding #21)

Reduction In Turnaround Time/Enhanced Flight Rate

In May 1985, a turnaround enhancement program was initiated formally with further emphasis added by senior management in December 1985. The following, excerpted from the Associate Administrator for Space Flight memorandum of December 23, 1985, is instructive:

"A primary overall program objective is to attain an STS turnaround timeline that supports a 20 flight/year rate from the Kennedy Space Center by FY 1989....We must take further positive actions to assure the required increase in the Space Shuttle flight rate which necessitates a steady reduction in turnaround activities...The change and modification work in the Orbiter Processing Facility has been highlighted as the key driver to reducing turnaround time and processing costs. To maximize our control of all changes, everyone must acknowledge the need that only those orbiter modifications (with few exceptions) which are mandatory for reliability, maintainability, and safety be accomplished between flights. Opportunity modifications should be scheduled and planning for scheduled block modification downtime periods for each orbiter.....Although I have primarily addressed the Kennedy Space Center portion of this initiative, we must also considered all elements of the system-wide capability and assess these also at this time".

During 1989, a great deal of attention again has been focused on all elements as well as the use of the Kennedy Space Center landing facility in lieu of the current primary landing site of Edwards Air Force Base in California.

The panel has only begun to evaluate the new turnaround enhancement program and will examine it in more detail during the next year. Because of the safety implications of such an activity, changes must be made very carefully with due regard to system as well as element involvement. There is a great deal to be said for in-flight checkout; for example, checkout of the hydraulic system on the orbiter during the mission to determine its fitness for the next mission thereby reducing turnaround time between landing and pad operations. With proper instrumentation the health of the orbiter hydraulics system, which includes the auxiliary power units, could be determined. However, the hydraulic system affects the Space Shuttle main engine thrust vector control system as well as the aerodynamic flight controls and the landing gear braking system.

Kennedy Space Center Processing Activities

There clearly have been improvements in the Kennedy Space Center system over the past few years. Morale is up and everyone seems to have a better handle on flight operations now that the Space Shuttle is flying again. However, there are areas that still require attention such as the extraordinary controls on shop aids. It is quite clear from talking with the technicians that many valuable small tools have been designed and used effectively, but their use had been forbidden due to lack of formal certification. Another is the volume of deviations and problem reports. There seems to be a clear need for a concerted effort to provide properly updated operations and maintenance instructions.

NASA and the support contractor leadership is stronger today than ever. However, the Space Shuttle Processing Contractor should take full advantage of their highly skilled and dedicated workers through closer ties between various levels of management and the hands-on personnel. This is of great importance to increase the effectiveness of a talented organization to reach the flight rate goals desired.

The "dual stacking" issue in the Vehicle Assembly Building has been discussed by the Space Transportation System organization for some time. To accommodate launch rates of nine or more a year would require stacking two sets of solid rocket boosters at the same time; and it appears that at the current flight rate, dual stacking to some degree is already occurring. Accepting the risk associated with single stacking or dual stacking appears reasonable if all personnel nonessential to the conduct of hands-on work are relocated to other areas outside of the Vehicle Assembly Building.

LOGISTICS AND SUPPORT

(Ref: Findings #22 through #25)

Overall, the logistics and support program for the Space Shuttle appears to be evolving well and a number of critical areas are being attacked energetically and effectively. The more important of these areas are discussed in the following paragraphs, but the general progress of the complex logistics program is considered to be good. Logistics support of the propulsion system (the external tank, solid rocket motors, and Space Shuttle Main Engines), which differs materially from the support required for the orbiter, is contracted and managed by the Marshall Space Flight Center.

Much of the parts and service support comes directly from the factory out of current production, and probably is not subject to the vicissitudes of multitudinous suppliers and sources to the same degree as the orbiter. However, the propulsion system in its entirety is really the heart of the Space Transportation System; logistically, its integration--to an economically sensible degree--is essential for the continued success of the Space Shuttle up to the year 2000 and beyond. Conversely, from some viewpoints, total and comprehensive integration for such a numerically small fleet of four orbiters in the long run may not be in NASA's best interest. It is important, however, that the many piece-parts needed for joining Space Shuttle elements be made the responsibility of the Kennedy Space Center.

The trend toward performing more component and unit overhaul, modification, and repair on-site at the Kennedy Space Center is clearly the right direction to reduce losses caused by pipeline and communication delays. It will lead eventually to reasonable self-sufficiency and less dependence upon occasionally indifferent suppliers of aging and highly specialized low production components.

Integrated Logistics Panel Activities

The Integrated Logistics Panel meetings have been expanded to coordinate more effectively the logistics activities between the principal NASA centers and respective contractor groups. The Aerospace Safety Advisory Panel has participated in several of these meetings. The Integrated Logistics Panel series now provide an effective forum for interchange and communication upon the whole spectrum of logistics and support and especially upon the progress being made upon some of the potentially "show-stopping" issues. The Panel is pleased to observe the widening scope and energetic use of the Integrated Logistics Panel as a principal management tool.

Logistics Management Transfer Responsibility

The NASA-requested transfer of logistics elements from Rockwell-Downey to the Kennedy Space Center has included program, business, and material management; and the transfer of the necessary personnel and systems has been essentially completed. In the material area, there will be a progressive transfer of issues such as subcontract management and procurement support, probably over the next 2 years. Quality assurance is almost complete; however, engineering activities will not be transferred from Rockwell-Downey. It is believed that all of the critical skills required have now been transferred from Rockwell-Downey and other divisions. The facilities formerly known as the Rockwell Service Center have been renamed NASA Shuttle Logistics Depot and a considerable number of component overhaul or repair certifications have been completed.

Supportability Trend, Analysis and Reporting System

This system, evolved by Rockwell in conjunction with the Johnson Space Center, meets the requirements of the relevant NASA documentation pertaining to general solid rocket motor and quality assurance. The Marshall Space Flight Center is moving towards providing the necessary data to enable this system to work in the manner required by the Kennedy Space Center.

Maintenance Trend Analysis Reporting System

This system provides a "picture of the health" of the Lockheed Space Shuttle Processing Contractor and the Rockwell-Downey and NASA Shuttle Logistics Depot activities. It is basically a monthly reporting system, covering the Shuttle Processing Contract and orbiter inventory management statistical data; flight and ground systems line replaceable units failures; orbiter, ground support equipment, and launch processing system failures as well as all flight and off-line hardware repairs processing data. These data illuminate such trends as orbiter cannibalizations, turnaround time, line replaceable units repair, and launch problems. The maintenance trend analysis report has been changed from an informal to a required formal document.

The Lockheed Shuttle Processing Contract Logistics Support Organization

Coordination between the Space Shuttle Processing Contract and Rockwell continues to be refined. One of the important facilities being coordinated jointly is the Logistics Critical Items Management Center, known colloquially as "lick-mick." It is a rough equivalent of the "Aircraft-on-Ground" control system used by the large commercial airlines which for NASA coordinates the critical items between Lockheed and Rockwell on behalf of the Kennedy Space Center. The function is performed by a dedicated four-man team for each orbiter. Flight hardware repair processing has been analyzed carefully and significant improvements made in handling, tracking, and statusing of unserviceable line replaceable units. Average time for documenting the disposition of unserviceable hardware has been reduced from 15 days to 5 days.

An extensive program of modifications to the ground support equipment and launch facility equipment has been completed. For orbiter and related modifications, a dedicated group of logistics personnel has been formed to process time compliance technical inspections, and establish status and tracking data.

Orbiter Carrier Aircraft--B-747

A program for supporting the Shuttle carrier aircraft is in place covering the needs for aircraft maintenance, modification, and logistics support. The principal airframe maintenance program is that of a continuous overhaul type used by the major commercial airlines. Engine maintenance is performed by specialists in accordance with the overall maintenance plan, which is coordinated by Boeing. Replacement engines are available from Pratt & Whitney within 24 hours and a similar aircraft-on-ground service is available from Boeing for the airframe.

The second Shuttle carrier aircraft is a short-range B-747 that is being modified to the standard of the current carrier aircraft and will be available in late 1990. NASA has access to the international airline spare parts pool. The entire program for the two Shuttle carrier aircraft appears to be well organized and the delivery of the second aircraft will give adequate assurance of reliable orbiter ferry support.

Cannibalization

Cannibalization has been the subject of intensive study and has been reviewed in several previous Aerospace Safety Advisory Panel annual reports. The cannibalizations are now fully reported in the maintenance trend analysis reporting system, affording visibility. A critical check list must now be satisfied item-by-item before a proposed cannibalization can be approved; and then, the action has to be signed off at the highest level at the Kennedy Space Center. This procedure and other control methods have been reviewed by the Panel and we are satisfied that adequate controls now exist. Since STS-26, cannibalizations have averaged less than five per vehicle.

Corrective Action Reports

Corrective action report completions are again causing difficulty. The backlog of corrective action reports has climbed significantly and this is an item of particular concern. Principal causes of the problem are: excessive time entailed from problem detection to failure analysis request, excessive time in the tear-down and failure analysis at the component manufacturer's facility, and also in the flight-by-flight review of the open corrective action reports. This problem is receiving attention at the highest level at all of the organizations involved.

Component Repair Turnaround Times

The major problem of excessive time entailed in the total cycle of component removal, fault or failure identification and analysis, repair, overhaul or rework, documentation, and shipment/shelf actions is being addressed by all the organizations involved. Spares management is holding weekly reviews, and periodic meetings are conducted with engineering to assess troublesome components and their manufacturers with a view to providing more rapid turnaround. Components are reviewed for disposition, failure analysis, or redesign. A "Red Team" has been established by Rockwell dedicated solely to the improvement of turnaround time. The team includes specialists on: spares management, engineering material, logistics operations support, and subcontracts. A logical review regimen has been established to conduct effective and comprehensive studies of audits and a list of the errant vendors has been compiled.

When examined in mid-1989, the combined average turnaround time for original equipment manufacturers and Rockwell activities was shown as 178 days per line replaceable unit and was expected to worsen over the next 9 to 12 months. The original equipment manufacturer average repair turnaround time had been as high as 238 days per line replaceable unit and some specific items were approaching double that value. The Panel cannot emphasize too strongly its concern over the problem of repair turnaround times and its potential effects upon spares holding with the increasing launch rates that are planned.

Space Shuttle Main Engine Logistics Status

The Marshall Space Flight Center and Rocketdyne manage all the logistics for the Space Shuttle Main Engines, most spares being supplied directly by the manufacturer. The history of spares requests versus those filled over recent launches looks very good although a rather high percentage of the 510 line replaceable units involved showed line items that are below minimum stock levels. A number of the units were at zero balance (meaning none in stock) and a recovery plan was put into effect that resulted in all of the green run hardware being shipped to the Kennedy Space Center.

The Rocketdyne repair depot provides support for the complete engine, especially the high pressure turbopumps. Significant reductions in assembly flow times for both pumps and the powerhead have been achieved over the past few years and recent powerheads have shown no weld discrepancies. Alternative sources have been studied for all components whose original equipment manufacturer may no longer be willing to provide support. In many cases, however, the development of alternative vendors could result in significant delays and cost increases. There is continuing concern about the limited number of spare main engines that are available. Rocketdyne has done a remarkable job of juggling engine hardware to meet operational requirements. The original planning for scheduled engine removals appears to have been based upon the design life specified for the main engine of 55 starts or 7-1/2 hours of operating time, but this is not being achieved. The present supply of spares for the high pressure fuel turbopump and the high pressure oxidizer turbopump is critical. This underscores the need for a concerted effort to drive the incorporation of any changes or procedures that would in any way enhance reliability.

Scheduled Structural Overhaul of the Orbiter Fleet

It is the opinion of the Panel that current documents do not provide a proper plan for scheduled structural overall for the orbiter fleet. A proper plan should entail overhaul and repair work divided into zones on the vehicle culminating in an out-of-service interval for major actions such as control surface removal, landing gear exchange, etc. Specific programs are needed to inspect for corrosion and heat damage, and the repair and replacement of fatigued structural parts. The Panel has commented on the need for such a definitive plan for several years. The Air Transport Association of America has recently performed sterling work in association with the Federal Aviation Agency and the airline industry to determine how to treat the problem of aging airframe structures; much could be learned from their work. Continued operation of the Space Transportation System into the higher launch frequencies contemplated--into the period of assembly and servicing of the Space Station Freedom--demands that no unpleasant surprises causing extensive stand-down should be encountered.

C. SPACE STATION FREEDOM PROGRAM

PROGRAM CONTENT

(Ref: Finding #26)

The Space Station Freedom Program is a very complex undertaking. It consists of a number of major elements, which are referred to as the work packages plus launch processing at the Kennedy Space Center. Each is managed by a NASA center with prime and subcontractor support. These functions include:

- Work Package #1 - habitation and laboratory modules
- Work Package #2 - truss, communications, and nodes
- Work Package #3 - flight telerobotic servicer and payload support
- Work Package #4 - photovoltaic power system
- Kennedy Space Center - launch processing

The task of conducting systems engineering analyses and achieving the integration of the total system--formidable activities--is the responsibility of the Space Station Freedom Program Office in Reston, Virginia. The Program Office has assigned staff members and contractor support at each of the NASA centers.

Severe cuts in the budget of the Space Station Freedom required NASA to reexamine the content of the technical baseline of the program, and make decisions as to adjustments in major changes and major deferrals. Such changes and deferrals can have an impact on operational safety and reliability. The following is a listing of those changes and deferrals.

Major Changes:

- Use of only DC power in place of mixed AC and DC power
- Hydrazine propulsion system for attitude and control in place of hydrogen/oxygen propellants
- One airlock in place of two airlocks
- Reduction in the laboratory support equipment
- Exclusive use of Space Shuttle space suits (no new high pressure suits)
- Deletion of test and development for a solar dynamic electric power system
- Passive cooling of external payloads instead of active cooling

Major Deferrals:

- 37.5 KW power capability initially, growing to 75 KW at assembly complete
- Reductions in crew habitability equipment with later enhancements
- Environmental control and life support system initially "open-loop" going to "closed-loop" oxygen and carbon-dioxide system
- Availability of ultra-pure water for science investigators
- Data communications capability of three 0-100 megabits per second initially, growing to eight units by assembly complete
- Availability of a user local area network onboard the station
- The global positioning system to be available by assembly complete

The Space Station Freedom presents unique design challenges that make early and complete definition of all design requirements extremely difficult. There are undoubtedly new design problems, some of which are yet to be discovered. This means that establishment of some of the design requirements will, as is normal, have to be evolved via an iterative process wherein the results of initial design and trade-off studies will lead to challenges and redefinition of the original requirements, and redesign as required.

TECHNICAL ISSUES

Space Environmental Factors
(Ref: Finding #27)

Orbital Debris

The dimensions of the orbital debris problem have received attention by NASA and other government agencies. A major contribution to an understanding of the issues involved was the "Report on Orbital Debris" written by the Interagency Working Group (Space) and issued in February 1989. Maintaining the impetus supplied by this activity, a NASA/DoD team continues to examine this area which is of major significance to any long duration space activity. There is a consensus that debris minimization should be a design factor for all future spacecraft and operations, and that more debris measurements are needed to further understand the hazard represented by the orbital debris environment. Thus, the recovery of the Long Duration Exposure Facility should be of invaluable help. With an orbital debris environment that is reasonably well defined, critical areas can be identified and (in some cases) hypervelocity impact tests can be conducted to better define the degree of hazard. Space Station Freedom designers, users, and managers then must determine what constitutes acceptable risk.

Radiation Shielding

This is another area that has been discussed and will continue to affect the design requirements of the Space Station Freedom as have the orbital debris issues. There is little concern with manning the Space Station Freedom on an appropriate crew rotation basis. However, substantial solar flare activity might require temporary evacuation if one adheres to conservative doses and dose rate limitations. This factor may also influence the choice of rescue system for the station, since it would favor the lifeboat concept. The cost of transportation to and from the Space Station Freedom is so high that personnel residence times must be months, not weeks, to be relatively economic. The result is that this group of people will almost certainly be exposed to more radiation than the normal government regulations for worker exposure would allow. It is not too early to start formulating new regulations governing this group of people and to make provisions for tracking them, so that later their career activities do not result in long-term overexposure.

The radiation problem and, indeed, the cost of maintaining people in space dictates that the Space Station Freedom be designed and automated so that it operates and maintains itself with only periodic inspections and service.

Ingress and Egress **(Ref: Finding #28)**

Space Shuttle - Space Station Freedom Docking

The current design of the Space Station Freedom has two hatches with which a Space Shuttle orbiter can dock. However, it is not possible for two orbiters to be simultaneously docked because the hatches are too close together. Should there be a failure in the docking mechanism that prevented separation of the orbiter from the station, the crew could become entrapped. Again, it is the singularity of egress that is of concern. It would be much safer if the second hatch were located in a manner that permitted two orbiters to dock simultaneously.

Airlocks

The decision to have a single airlock created a Criticality 1 single-failure-point that in turn has an adverse effect on the risk associated with ability to egress from the station in the case of a dire emergency. For example, the ability to have an assured crew return capability is compromised. This is especially true when the crew complement reaches eight rather than the initial crew of four or less in the early stages of assembly of the station. The present design appears to provide only for egress to a docked Space Shuttle orbiter without the need for extravehicular activity. If there are credible scenarios under which internal vehicle access to an orbiter may not be possible or in which an orbiter has damaged the docking port, the deletion of the second airlock certainly increases the chance that a crew extravehicular activity transfer will be necessary. It is not clear what means of egress for the entire crew are possible in the event of a power failure. All of these issues underscore the need for a crew emergency return vehicle (or other similar vehicle). The Panel believes that the second airlock should be reconsidered as a necessity to enhance the safety of the overall Space Station Freedom operations during assembly and after completion of construction.

Internal Environment

(Ref: Finding #29)

Toxic/Hazardous Spills

A primary goal of the Space Station Freedom is zero-g experimentation and development of all types of materials. There may be many activities using materials that can be detrimental to crew health and well-being as well as to the station itself. Thus, it is necessary to consider the options available to eliminate, control, and/or alleviate the effects of such materials getting into the station atmosphere/surfaces, thereby adversely affecting the safety of the total operation. It is not enough to state in the requirements that spills shall not occur since in a 30-year lifetime it is a statistical likelihood. Early in the design of the basic station, and any payloads it will carry internally, is the time to assure that system safety activities include this aspect in their analyses.

Fire In Zero-G

An area of interest to both the Panel and NASA has been the efforts associated with defining and understanding fire detection, fire prevention, and fire extinguishment in spacecraft under zero-g or near weightless conditions. NASA Headquarters established a Spacecraft Fire Safety Steering Committee, which was discussed in Aerospace Safety Advisory Panel's annual report issued March 1988. An organizational meeting of this committee was held in June 1989; however, it has been noted that little activity has taken place since that time. Components of spacecraft fire safety strategies include the following:

- Fire prevention: material screening, safe operations, risk analyses
- Fire responses: hazard detection, incipient fire suppression, alarms, decision models
- Fire recovery: spreading fire extinguishment, crew evacuation, post-fire cleanup

The status of spacecraft fire safety was stated as:

- Current policies and procedures appear adequate for short-duration missions.
- The science of fire in microgravity is reasonably well understood.

- More information is needed regarding the increased hazards due to long duration.

A comparison of preliminary fire protection proposals for Space Station Freedom laboratories is shown in Figure 7. There are several key issues regarding fire detection and suppression for the Space Station Freedom that should be addressed as soon as practical. Standardization or commonality of fire detection and suppression systems among the Space Station Freedom members is most important. This involves standardization of detectors and their sensitivities, caution and warning criteria, extinguishing agents and criteria to show that fire is truly suppressed.

Common Berthing Mechanism

(Ref: Finding #30)

The "common" berthing mechanism appears in three forms: active rigid, passive rigid, and passive flexible as shown in Figures 8 and 9. The design and development of these mechanism are significant to both the NASA work packages and the international partners who will be attaching their laboratories to the basic station configuration.

Extravehicular Activities

(Ref: Finding #31)

Every aspect of the Space Station Freedom assembly and operational use includes extravehicular activities to varying degrees. During the assembly missions, the interplay of the Space Shuttle orbiter with the components being fashioned into the Space Station requires a great deal of extravehicular activity even with the help of the remote manipulator system in the orbiter and the telerobotic servicer on the station. The current plan is to use only the Space Shuttle space suit (low pressure requiring prebreathing and limited work time availability) rather than to develop a

LABORATORY	LABORATORY RACK FIRE DETECTION	MODULE FIRE DETECTION	EXTINGUISHING AGENT	EXTINGUISHING SYSTEM
U.S. (BOEING)	SMOKE + THERMAL	SMOKE + FLAME	CO_2	CENTRALIZED + ADDITIONAL PORTABLE
COLUMBUS (E.S.A)	SMOKE + T.B.D.	T.B.D.	HALON 1301 (CO_2 ALTERNATIVE)	DISTRIBUTED (INDIVIDUAL BOTTLES) + PORTABLE
JAPAN (NASDA)	SMOKE + THERMAL	SMOKE + FLAME	CO_2 (HALON 1301 ALTERNATIVE)	DISTRIBUTED (INDIVIDUAL BOTTLES) + PORTABLE

Figure 7, Comparison of Preliminary Fire-Protection Proposals for Freedom Laboratory Modules

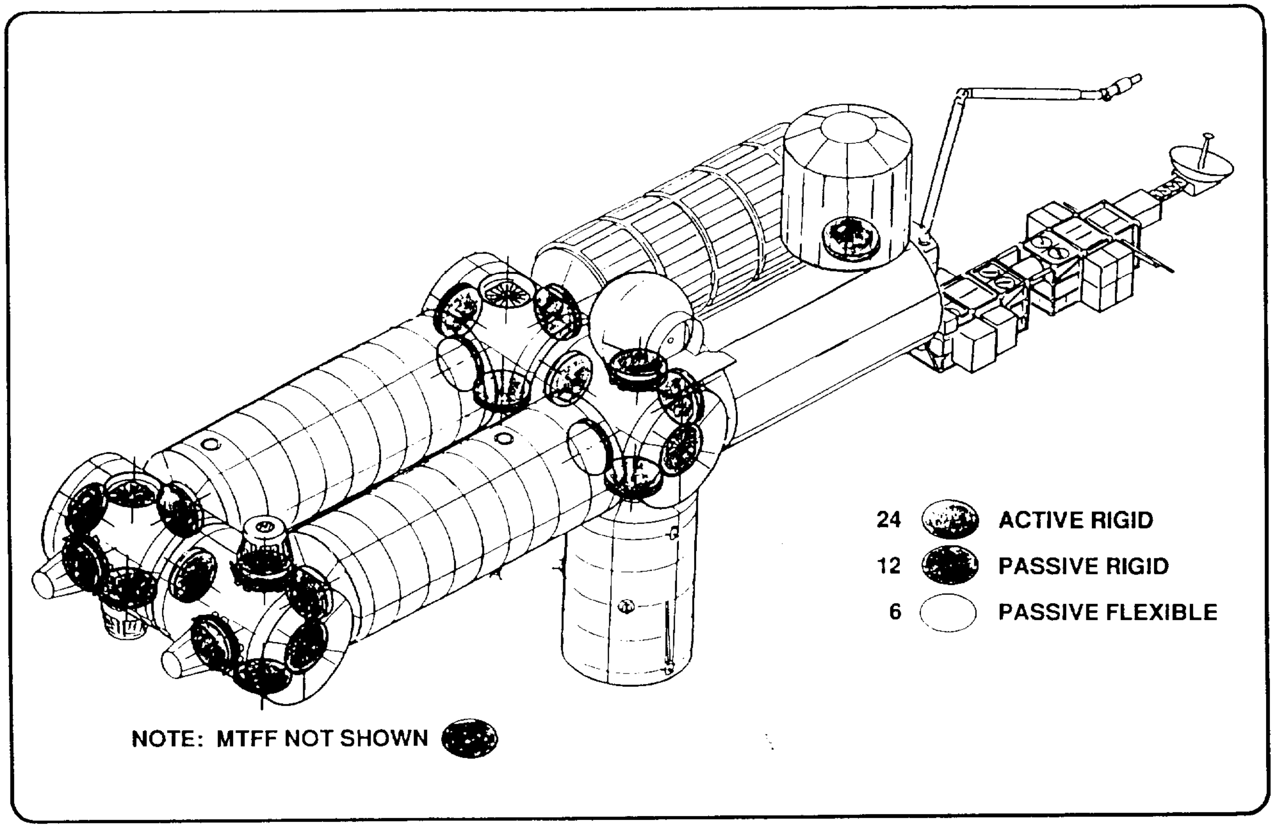


Figure 8, Common Berthing Mechanism Locations

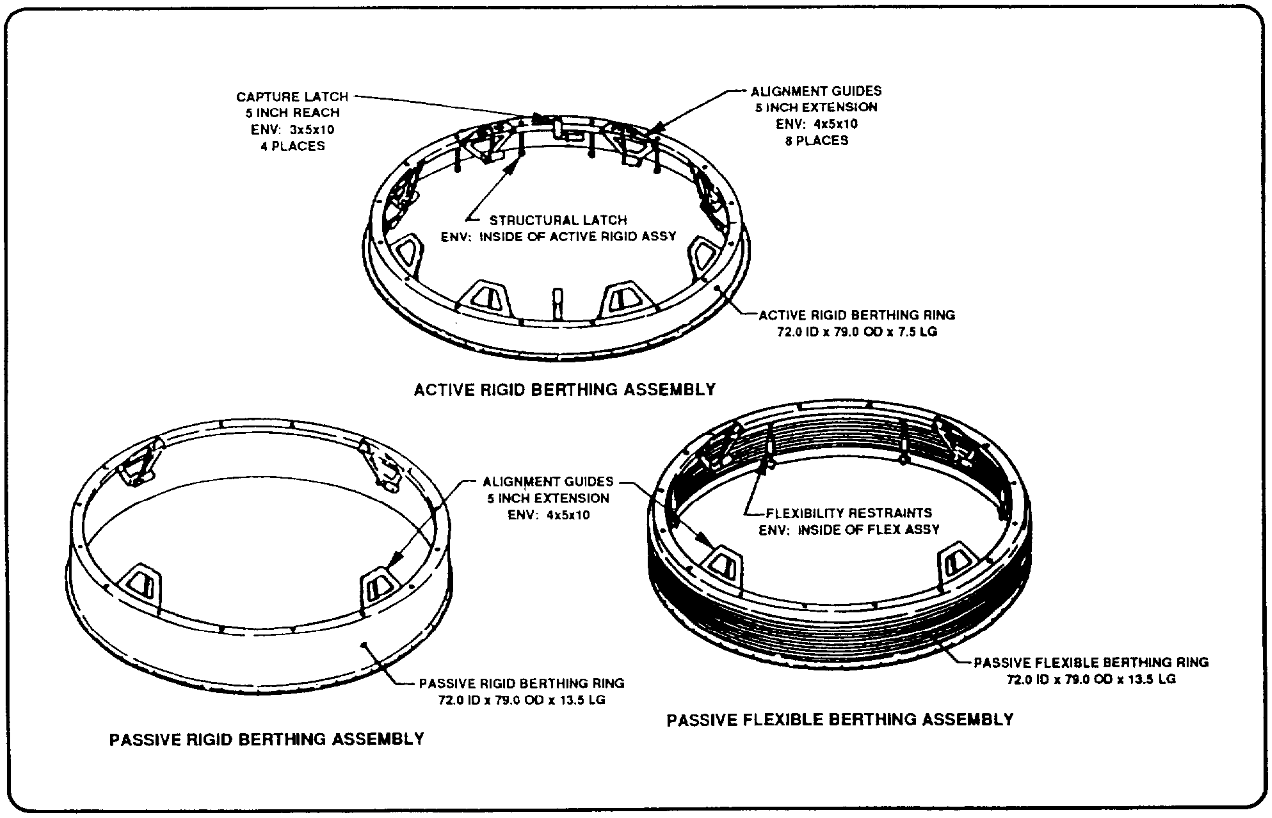


Figure 9, Common Berthing Mechanism Overview higher pressure suit that is more adaptable to the requirements of the station assembly and long-term operations. Use of the current suits places a very rigid set of requirements upon the station design, training, operations, and emergency reaction processes. The current suit is tailored to the individual astronaut. Further, it requires a long period of prebreathing 100 percent oxygen before conducting an extravehicular activity and must be certified for uses beyond that now stated. Also, the current suit must be serviced on the ground after about three uses. The glove or effector part of the suit does not lend itself well to extended periods of hand activities such as required during the assembly of the station. There is a desire to use the flight telerobotic servicer unit to supplement the crew extravehicular activities, but this has yet to be proven viable. It certainly appears to be prudent to make every effort to obtain funds to continue the development of the higher pressure suit so that it can be phased in at some later date, either before station assembly is complete or at least during the operational period of the station.

Safety and Product Assurance

(Ref: Finding #32)

The safety and product assurance activity for the Space Station is similar to that applied on the Space Shuttle. However, given the many interfaces the station has, and the geographical spread of the activity, there is some difficulty in assuring an integrated, meaningful safety and product assurance activity. In general, it might be well to apply the following concepts to the safety and product assurance activity throughout the various levels of the Space Station Freedom Program:

- The safety and product assurance organization should be situated within each level at an appropriate organizational position to assure access to program management and have enough clout to be heard within the engineering and associated disciplines.
- The safety and product assurance personnel should be a true team member within systems engineering and integration operations, since their activities (especially in the early phases of design work) are crucial to minimizing hazards and overall risks before they become ingrained in the design and operations.
- A strong subcontract management organization is required at the contractor level to assure that acceptable products come into the prime contractors.
- Total Quality Management should be considered as a normal part of the daily operations of the safety, reliability, maintainability and quality assurance organizations of all levels of the Space Station Freedom. NASA continues to have a vibrant program intended to imbue every aspect of NASA with total quality management just as is being done in other agencies and the aerospace industry.

Contingency Planning

(Ref: Finding #33)

An important area to station safety is the effort associated with defining and understanding contingency operations and their effect on overall design. An approach that is suggested includes:

- Develop selected scenarios to the level of detail sufficient to identify appropriate crew or ground responses for immediate safing action, and subsequent isolation, restorative or rescue action; system/element design requirements to enable the above;

and configuration/assembly changes required to assure crew safing and survival.

- Develop the methodology that includes selecting Space Station Freedom assembly mission configurations, defining the emergency, and identifying configuration capabilities and actions to resolve the contingency.

- Establish the major ground rules and assumptions for this work. There is no need in the early stages to assess the probability of occurrence or the criticality of events, and the emphasis is on identifying system design requirements to enable appropriate crew or ground response to scenarios.

Safety-Critical Functions
(Ref: Finding #34)

Space Station Freedom designs are being postulated and developed without what appears to be sufficient upstream analyses in the sense that there is a lack of thorough functional analysis. For example, when the various work packages are preparing lists of crew safety essential functions, they cannot make reference to an accepted project-wide list of basic critical functions.

There appears to be significant confusion between functions and systems. This is partially because there has been no organized functional analysis of the total system by the systems engineering and integration people as a precursor to the development of requirements for design and safety.

Space Station Freedom Computer Systems **(Ref: 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 those computers. These computers will operate in real time and control many other devices. There is no known theory of software testing that is adequate to guarantee that the software is correct. For the Space Shuttle, this difficult problem is dealt with thorough massive testing using actual flight computers and as much real hardware as possible. For the Space Station Freedom, the software will be much larger and more complex than for the Space Shuttle. The problem is compounded because there will be in-space modifications to the computers and software of a nature not present in the Space Shuttle computer systems. Both software and hardware will have to be upgraded 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 environment of the Space Station Freedom itself. Initially, it was intended that the test environment would consist largely of the various Space Station Freedom components, with actual hardware included where feasible. More recently, the form of the testing facility has been altered to replace hardware with simulations.

LOGISTICS AND SUPPORT

The Space Station Freedom, unlike the Space Shuttle, will be permanently in flight on-orbit and is expected to remain so for decades. Comparing this requirement to those applicable to the up-and-down Space Shuttle, which has multiple facilities and ground transportation to meet logistics requirements, it is obvious that the Space Station Freedom requires a different approach to both design and operation.

The challenges and possible solutions to meet them have been put forth by various Space Station Freedom organizations (refer to Figure 10 for typical examples of challenges and possible solutions).

Two aspects of logistics, availability and supportability, are now a part of the lexicon. Availability means a system or function is available for a specified use; and is a function of: mean time between maintenance actions, mean time to restore, and mean time between failure. Supportability are those program support aspects necessary to ensure that the operational system continues to perform its intended mission over a specified period. A composite of all support aspects necessary to assure the effective and economical support of the Space Station Freedom throughout its intended life is termed "integrated logistics support." Supportability includes the following:

- Currency of planning maintained to meet changing requirements.
- Personnel and their training.
- Initial provisioning and then resupply, including hardware return to earth.•Test and ground support equipment, facilities, ground handling and transportation.

CHALLENGES	POTENTIAL SOLUTIONS
LIMITED CREW MAINTENANCE TIME	DESIGNED IN REDUNDANCY
	BIT/BITE
	ROBOTICS
	PROPER STOCKAGE OF CRITICAL SPARES IN CLOSE PROXIMITY
	DEFER MAINTENANCE ON LOW CRITICALITY
LIMITED STORAGE FOR SPARES ON ORBIT	STOCK ONLY MOST CRITICAL SPARES ON ORBIT
	DEFER MAINTENANCE UNTIL SPARES ARE RESUPPLIED
	REDUNDANCY IN DESIGN TO PERMIT REPLACEMENT UNITS AVAILABILITY
COSTLY RESUPPLY/RETURN CHAIN	REDUCE SIZE, VOLUME, WEIGHTS OF SPARES
	POSSIBLY DO LOWER LEVELS OF REPAIRS TO MINIMIZE REMOVING/REPLACING/RETURNING COMPLETE ORUs
PRODUCTION CAPABILITY FOR RESUPPLY	TRADE-OFFS TO MAINTAIN PRODUCTION CAPABILITY VERSUS ALTERNATE SOURCES OR LIFETIME BUYS
LIFETIME BUY VERSUS OBSOLESCENCE	TRADE-OFFS TO BUY, MODIFY, UPGRADE, MAINTAIN CURRENT CONFIGURATION VERSUS SCRAP AND REPLACE WITH NEW CONFIGURATION

Figure 10, Space Station Logistics

- Technical data and computer resources.

Meeting the Space Station Freedom and payload supportability requirements with the limited resources currently known to be available will present a great challenge to the Level III and IV work package organizations.

Two points should be made: First, many spare parts for the Space Station Freedom will have long lead times, and all spares will have to compete for limited launch payload space. There is, therefore, a potential for unexpected failures of station orbital replaceable units without the availability of spares. Spare orbital replaceable units for the station should be baselined early in the development process. In addition, the spares availability and the launch manifest to deliver them on orbit should be included in the launch commit criteria for the Space Station Freedom.

Second, the basic resupply philosophy for Space Station Freedom involves replacement of orbital replaceable units launched from the ground. Faulty or expended orbital replaceable units are to be returned to the ground for refurbishment or disposal. This approach raises the possibility that unscheduled maintenance due to component failures could create a situation in which the Space Shuttle downmass capability would have to be exceeded to return both the scheduled and unscheduled orbital replaceable units.

The most recent operations scenario calls for a higher flight rate during operations than during assembly. This means pressurized logistic modules will be in a continuous ground turnaround mode: de-integrate, repair/refurbish, repack, reverify, and launch; Also, there will be two pressurized logistics modules in this cycle with one on-orbit. Additional cargo carrier requirements have been added to the program for supercritical N_2 and O_2 as well as hydrazine. All of these carriers must be processed, stored, and treated as any other flight hardware. A Japanese logistics module also must be accommodated in addition to the United States logistics module, although on a less frequent turnaround. Another significant space user is large attached payloads.

Although not designated as a work package center, the Kennedy Space Center has all the earmarks of a work package and should be given formal recognition as a work package center. The Kennedy Space Center is tasked with support/implementation of payload formulation and processing for launch on the Space Shuttle. This includes the Space Station Freedom processing facility, ground support equipment development, and the test control and monitor system development. As the Space Station Freedom Program matures, there will be a tremendous challenge for systems engineering, integration, and assembly definition to meet the capabilities of the Kennedy Space Center as the launch processing center.

It is understood that at the appropriate time, the Kennedy Space Center civil service operations personnel will participate during factory checkout of flight hardware from start of subsystem testing through final acceptance.

It was planned to establish Kennedy Space Center Resident Offices at work package centers (Marshall Space Flight Center and Johnson Space Center) to facilitate and enhance the implementation of tasks to manage the ground support equipment. This has not occurred as yet. If these offices are established, they would enhance interface and coordination with and understanding of all program activities. The Kennedy Space Center indicates it will continue to assess its need for resident offices. Work package centers currently have resident representatives at the launch site. In the long term, all work packages will be in residence at the launch site during hardware processing, both civil service and contractor.

D. AERONAUTICS

AIRCRAFT MANAGEMENT

(Ref: Findings #36 and #37)

Effective August 28, 1989, the Aircraft Management Office was reassigned to the Logistics and Security Office at NASA Headquarters. This has once again degraded the level of the Headquarters Aircraft Management Office. Although NASA continues to stress safety in its space operation, it appears to take for granted the safety of atmospheric flight. Instead of a true focal point at Headquarters for the development and establishment of policy relating to safety of flight, NASA continues to rely solely on the Intercenter Aircraft Operating Panel for the establishment of flight operational rules and regulations. This panel has done an excellent job, but must in turn rely on a central staff at Headquarters to coordinate these efforts and establish system-wide operational policies.

The downgrading of this Headquarters group implies that NASA has no real interest in overall aviation safety policy until such time as an accident occurs. Then the interest usually rises and gets high level attention. The ASAP recommendations made in our annual report for 1987 indicated a lack of clear understanding as to which group in NASA was responsible for the various aspects of aviation policy, both for administrative aircraft and for vehicles involved in flight test programs. The Panel's concern is evidenced by the letter to the NASA Administrator dated April 29, 1987, expressing concern about a reorganization proposal affecting the Aircraft Management Office.

On June 8, 1987, the NASA Administrator sent a letter to Mr. Norman R. Parmet, Deputy Chairman, Aerospace Safety Advisory Panel, in which he stated:

"Let me assure you that flight safety remains a paramount objective of NASA. It is being pursued, as you know, in our new Office of Safety, Reliability, Maintainability, and Quality Assurance, as well as in the Aircraft Management Office which is in the Office of Management. While I have not yet received the latter Office's reorganization proposal for formal approval, ***I can assure you that the Aircraft Management Office will continue to report to the Associate Administrator for Management.***" **(emphasis added)**

Flight recorders are in common use throughout the air transport industry. Such recorders are used to permit the collection and evaluation of trend data on aircraft system performance as well as flight crew performance. The data are utilized to provide support for design improvements as well as improved operating procedures, particularly where safety of flight is indicated. In this way, a tool is provided to assist in accident prevention. Regular analysis of data is necessary for effective use of flight data recorders. The other principle use of flight recorders is in analyzing aircraft accidents. The recorder the provides operational data that existed at the time of an incident or accident and provides a basis for ensuing investigations.

Research aircraft normally have adequate flight recorders as do some of the administrative aircraft used for carrying personnel. The astronaut training aircraft do not have flight recorders. The absence of these recorders is an impediment to safe operation. This condition should be rectified.

AERONAUTICAL RESEARCH

Of the many flight research projects ongoing at the Dryden Flight Research Facility, Langley Research Center, and Ames Research Center, the ASAP was only able to cover the activities associated with the X-29 program. Other projects were reviewed more to maintain a feeling for how they were progressing. In the coming year, more time will be allocated to the research and development aircraft projects that appear to present advanced state-of-the-art. Consequently, there will be an increased probability of safety issues arising from these reviews.

One project of particular interest is the Convair 990 landing systems research aircraft, which has an orbiter-like landing gear system attached to its fuselage and will be used to examine the tire, brake, wheel system of the orbiter under actual flight/landing conditions.

With regard to the X-29, ASAP interest centered on the flight readiness review process for the new high angle-of-attack program. The purpose of this program is to quantify aircraft design benefits of the X-29 technologies in the high angle of attack flight region, and to evaluate the military utility of the technologies. Specific objectives of the program are to evaluate aircraft maneuvering, flying qualities, and control characteristics. Test results are to be compared to predictions for validation of the design methodologies.

The flight readiness review included independent teams: the NASA team consisting of members of the Air Force Flight Test Center, a test pilot, technical specialists and an operations specialist; and a second team from the Air Force Systems Command, the "Aeronautical Systems Division Executive Independent Review Team."

The flight test program is a follow-on to the X-29A-1 (first X-29), which opened the aircraft envelope with a total of 242 flights and 200 flight hours. The first aircraft was not flown past an angle of attack of 22.5 degrees and performed only mild maneuvers. To perform military-type maneuvers, several major modifications were made and incorporated in the second aircraft. Significant modifications include the following:

a. ***Flight Control System*** - The control law software was modified to meet the high angle of attack control law requirements.

b. ***Angle of Attack Measurement System*** - The fuselage-mounted side probes used on the first aircraft would generate erroneous data for angle of attacks greater than 30 degrees. Therefore, two new nose boom angle of attack vanes were added to the existing vane, each powered by an individual flight control computer to have redundancy. The instrument panel was modified to show pitch and yaw rates.

c. ***Spin Chute System*** - A spin chute has been added to provide recovery capability from a fully developed erect or inverted spin and deep stall. The chute is jettisoned by a mechanical system with a pyrotechnic backup.

d. ***Spin Recovery Lights*** - A set of recovery lights has been added to the center of the main instrument panel to show direction of recommended pilot input to recover from the spin.

e. ***Inertial Navigation System*** - This has been installed to gather reliable angle of attack, sideslip, and velocity data at very high angle of attacks and low airspeeds.

f. *Emergency Power Unit* - The emergency power unit will furnish hydraulic and electrical power in the event of primary system failure. It will be operated continuously during the high angle of attack operations.

All of the above indicate the degree to which steps have been taken to assure not only accurate and useful flight data, but safe operation. Since the fundamental aerodynamic control and stability of the aircraft are critical to the safety of the program, a considerable amount of time has been spent reviewing the very comprehensive analytical and simulation activities. In general, the aircraft appears to be spin-resistant and no spins are predicted if the controls are in an anti-spin position. The spin tunnel tests indicate a marginal recovery from an upright flat spin; however, the spin chute will provide for recovery from the upright flat spin. Simulation has indicated the possibility of an authoritative pitch mode (a tumble). This might occur at high sideslip angle combined with high roll and nose down pitch rates. The rotational inertia allows rotation to proceed through the stable regions and then the aircraft would continue to tumble. Analysis indicates this departure will be unlikely if the active stake is used to counter the rotational motion. Another concern investigated was the possibility of engine failure (flameout/shutdown) due to large angle of attack combined with high sideslip. The engine/inlet compatibility at the high angles is not really known, but the F404 engine does have excellent stall/recovery characteristics. The test program calls for expanding the flight envelope in a gradual buildup to discover any adverse tendencies before they can produce flameout. This is tied in with the emergency power unit, which makes this even more of a concern. In this connection, the system safety and hazard analysis identified the emergency power unit failure during engine-off as a probability of 4 x 10^{-4}, and since this condition would cause loss of the aircraft it has been classified as a Category 1C hazard. A Category 1C hazard is defined as a hazard that is likely to occur at some time during the program and that has an associated probability of greater than 1 x 10^{-6} (one in a million chance). This is an area receiving further attention. This section is presented to indicate the depth of risk assessment conducted prior to flight of any NASA research aircraft.

E. RISK MANAGEMENT

(Ref: Findings #38, #39 and #40)

For programs that have very ambitious performance goals, utilize high technology levels and involve large dollar expenditures, it is essential that a major effort be established to identify and reduce risks early in the life of the program. The risk management system employed must have the capability to deal with and minimize safety risks in the context of technical, cost, and schedule uncertainties.

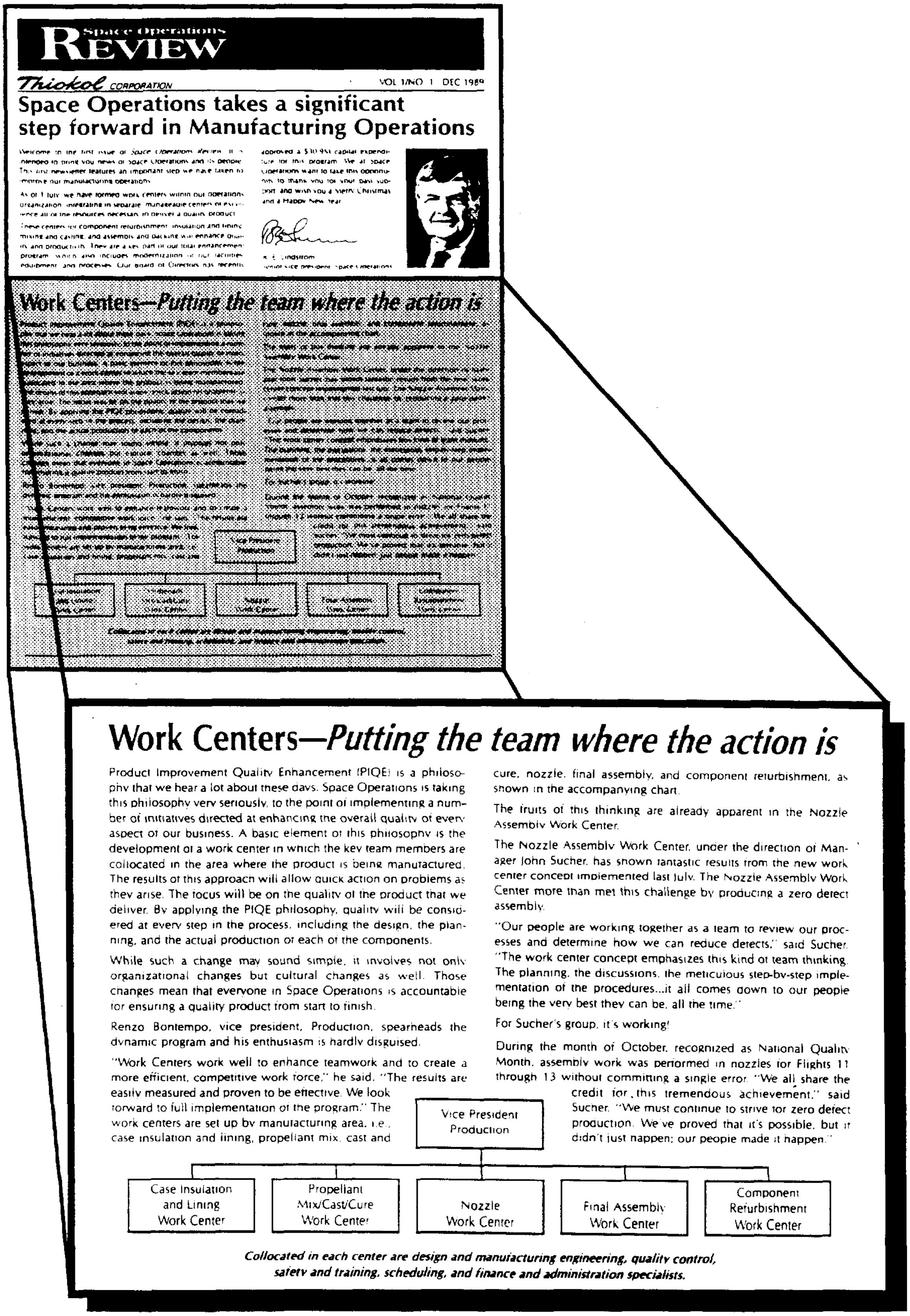
Risk management involves consideration of the relative risk of alternatives and the minimization of risk consistent with the prevailing state of the art and existing resource constraints. Although there are various types of risks of importance to NASA, safety risk is of prime concern to the Panel. It is considered essential that each of NASA's major programs as well as the Agency as a whole maintain a consistent and functionally effective program of risk management.

To conduct an adequate program of risk management, it is necessary to understand and apply appropriate risk assessment techniques. However, it is not essential that these techniques always be detailed and quantitative. The rigorous and consistent application of qualitative risk assessment approaches can be a cost-effective approach when sufficient data are not available to support more quantitative, probabilistic approaches. Quantitative risk assessment has the most impact during conceptual definition and preliminary design when the designer is trying to select a preferred system. The procedures can be kept simple and <u>precise</u> statistical information is not needed to identify risk areas in a disciplined way that quantifies the risk levels of the design selected. Early determinations of comparative risks between competing designs can be derived from a model that assigns numerical values to two variables (uncertainties and criticality), for the design elements, which are then combined to produce an overall numerical risk level. This type of risk assessment model should allow all levels of the project to make proper decisions regarding risks. The key to efficient and effective risk management is the consistent and timely application of the most appropriate techniques, whether qualitative or quantitative, to ensure that relative safety risk is thoroughly considered in management decision-making.

The Panel believes NASA can do more through its management issuances to promote the application of consistent risk assessment and management approaches in all of its programs. Relative risk metrics should be a routine part of management reporting.

The Aerospace Safety Advisory Panel has stated many times that the art and implementation of communications is a centerpiece of an effective Safety, Reliability, and Quality Assurance Program. An example of this can be seen in the new approach taken by the new management team at the Thiokol Corporation, manufacturer of the redesigned solid rocket motor, as illustrated in their "Space Operations Review," shown in Figures 11A and 11B. Two important items are highlighted: putting the Product Improvement Quality Enhancement (PIQE) philosophy to work, and a unique incentive program that not only attracts the employees, but in reality the whole surrounding community. To varying degrees similar programs have been established at other contractors and at NASA centers to further the cause of safety, reliability, and quality assurance especially in the manned space programs. It is important that innovative ways be found to maintain the initial impetus provided by such activities.

The Space Shuttle Program has a need to monitor the aging of components and their reliability as a function of time in service. This typically 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. Statistics on single fleet leaders should be augmented by simple data that identifies the distribution of the entire fleet. For items procured in relatively large numbers, this might be expressed as 25th, 50th (median), 75th and 95th percentile figures. For relatively unique items, information on the three or four oldest and youngest item might be provided.



Space Operations

REVIEW

Thiokol CORPORATION VOL 1/NO 1 DEC 1989

Space Operations takes a significant step forward in Manufacturing Operations

Welcome to the first issue of *Space Operations Review*. It is intended to bring you news of Space Operations and its people. This first newsletter features an important step we have taken to improve our manufacturing operations.

As of 1 July we have formed work centers within our operations organization, integrating in separate, manageable centers of excellence all of the resources necessary to deliver a quality product.

These centers for component refurbishment, insulation and lining, mixing and casting, and assembly and packing will enhance quality and productivity. They are a key part of our total enhancement program, which also includes modernization of our facilities, equipment, and processes. Our Board of Directors has recently approved a $30.9M capital expenditure for this program. We at Space Operations want to take this opportunity to thank you for your past support and wish you a Merry Christmas and a Happy New Year.

R. E. Lindstrom
Senior Vice President, Space Operations

Work Centers—*Putting the team where the action is*

Product Improvement Quality Enhancement (PIQE) is a philosophy that we hear a lot about these days. Space Operations is taking this philosophy very seriously, to the point of implementing a number of initiatives directed at enhancing the overall quality of every aspect of our business. A basic element of this philosophy is the development of a work center in which the key team members are collocated in the area where the product is being manufactured. The results of this approach will allow quick action on problems as they arise. The focus will be on the quality of the product that we deliver. By applying the PIQE philosophy, quality will be considered at every step in the process, including the design, the planning, and the actual production of each of the components.

While such a change may sound simple, it involves not only organizational changes but cultural changes as well. Those changes mean that everyone in Space Operations is accountable for ensuring a quality product from start to finish.

Renzo Bontempo, vice president, Production, spearheads the dynamic program and his enthusiasm is hardly disguised.

"Work Centers work well to enhance teamwork and to create a more efficient, competitive work force," he said. "The results are easily measured and proven to be effective. We look forward to full implementation of the program." The work centers are set up by manufacturing area, i.e., case insulation and lining, propellant mix, cast and cure, nozzle, final assembly, and component refurbishment, as shown in the accompanying chart.

The fruits of this thinking are already apparent in the Nozzle Assembly Work Center.

The Nozzle Assembly Work Center, under the direction of Manager John Sucher, has shown fantastic results from the new work center concept implemented last July. The Nozzle Assembly Work Center more than met this challenge by producing a zero defect assembly.

"Our people are working together as a team to review our processes and determine how we can reduce defects," said Sucher. "The work center concept emphasizes this kind of team thinking. The planning, the discussions, the meticulous step-by-step implementation of the procedures...it all comes down to our people being the very best they can be, all the time."

For Sucher's group, it's working!

During the month of October, recognized as National Quality Month, assembly work was performed in nozzles for Flights 11 through 13 without committing a single error. "We all share the credit for this tremendous achievement," said Sucher. "We must continue to strive for zero defect production. We've proved that it's possible, but it didn't just happen; our people made it happen."

Collocated in each center are design and manufacturing engineering, quality control, safety and training, scheduling, and finance and administration specialists.

Figure 11A, Space Operations Review

Space Operations receives 1989 *Franklin Award*

Each year, and for the past 15 years, Thiokol Corporation has bestowed the *R.D. Franklin Award for Outstanding Technical Achievement*. This year that award went to Space Operations.

The award is given in memory of Robert D. Franklin, an employee of our Huntsville Division who was highly regarded and held responsible positions in program management and research and development. He worked throughout the company making many significant contributions which helped give us our technological edge in the industry. Franklin passed away in his 40s.

In the past, the award has usually gone to a specific group within a given division or business unit. However, this year's award was given to the entire Space Operations organization. In announcing the winners of this year's award, U.E. Garrison, president and chief executive officer, said: "It is with a great deal of appreciation and a distinct pleasure to inform you that Space Operations' completion of RSRM qualification and return to flight has been selected as the outstanding technical achievement of 1989.

"Your organization assembled an outstanding technical team to support the Rogers Commission investigation, redesign the SRM, and then develop and qualify the RSRM. Never in my experience have we mounted and completed such an effort in so short a time. That effort culminated in return to flight in September of 1988 and completion of qualification earlier this year. Such an achievement required the effort of a great many dedicated people working long hours over a three-year period. Their achievements were truly outstanding and will be even more valuable in the years to come, not only to the Corporation but to NASA and the nation as well.

"It is therefore my privilege to recognize such achievement and effort by announcing that Space Operations is the recipient of the 1989 *R.D. Franklin Award for Outstanding Technical Achievement*."

At your service—Bill Askew and Wayne Tackett

Bill Askew and Wayne Tackett have recently been assigned to the Huntsville office of Space Operations.

Bill, a 30-year veteran of NASA, will manage the office, and Wayne will manage the business development end of the operation in Huntsville for Space Operations.

Bill came on board with Space Operations last summer. His last position at NASA was deputy manager, Shuttle Projects Office.

Wayne is a 10-year employee of Thiokol and has held various positions throughout Space Operations ranging from design engineer to managing new business contracts.

Both gentlemen are looking forward to the opportunity to serve you any way they can. Don't hesitate to call at (205) 534-2485 or drop in to see them at 2707 Arnie Street, Suite 7, Huntsville, Alabama 35805.

Bill Askew

Wayne Tackett

News notes from Space Operations

Al McDonald receives Distinguished Exec Award—Al McDonald, vice president, Advanced Programs and Technology, recently received the Distinguished Executive Award from Utah State University's College of Business. He was recognized by the university for his outstanding managerial achievements at Space Operations.

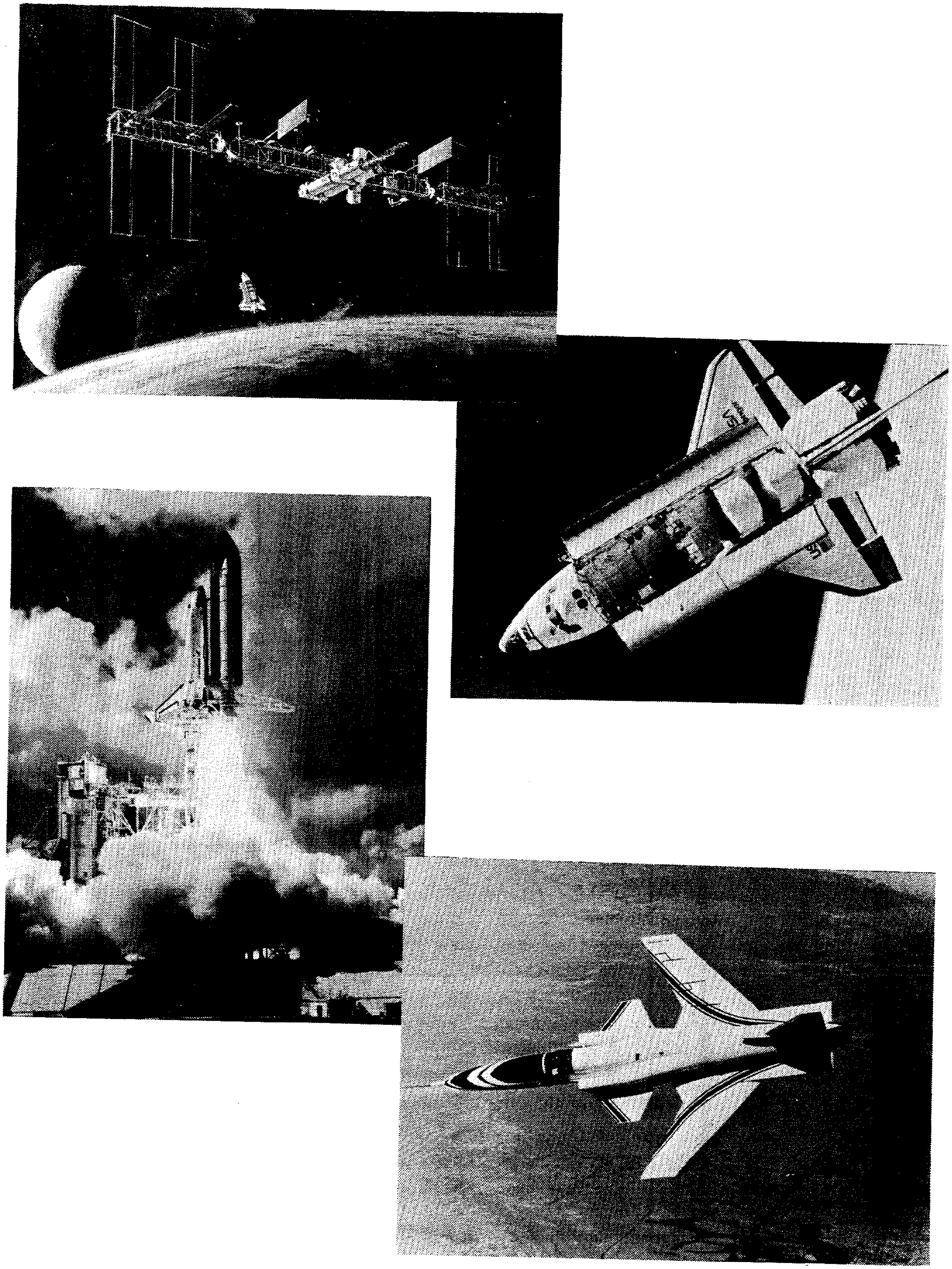
Michael Todaro is new director of HR—Mr. Todaro joined Space Operations on 13 November as director of Human Resources. Todaro comes to us from Rohr Industries in San Diego, California where he served as that company's director of Human Resources.

No anomalies found on STS-33's flight set—No in-flight anomalies were found on redesigned solid rocket motor flight set No. 7 used to lift off STS-33 in October. This was the first time in the RSRM's short history that no new in-flight problems had cropped up. The results are encouraging, and are indeed another display of our commitment to PIOE at Space Operations.

Safety is Priority One!—Incentive program helps—We decided a regular incentive "bonus" would be one way of keeping the importance of safety awareness at the forefront of everyone's mind. We also came up with a unique way of presenting this bonus. Each person in Space Operations received ten $2.00 bills in October as a reminder that safety really does pay! Then again, in November, another bonus was handed out in the same distinctive fashion. In all, over $170,000 was given to our people, helping them to keep safety awareness the top priority at Space Operations.

The $2.00 bills also made an impact in the Northern Utah communities. As the large number of the unusual bills were spent, local communities became aware of our commitment to safety as well.

Figure 11B, Space Operations Review



IV. APPENDICES

A. NASA AEROSPACE SAFETY ADVISORY PANEL MEMBERSHIP

CHAIRPERSON

MR. JOSEPH F. SUTTER
Former Executive Vice President
Boeing Commercial Airplane Company

DEPUTY CHAIRPERSON

MR. NORMAN R. PARMET
Aerospace Consultant
Former Vice President, Engineering
Trans World Airlines

MEMBERS

MR. CHARLES J. DONLAN
Consultant
Institute for Defense Analyses

MR. GERARD W. ELVERUM, JR.
Vice President/General Manager
TRW Applied Technical Division

DR. NORRIS J. KRONE
Executive Director
University Research Foundation
University of Maryland

MR. JOHN F. MCDONALD
Former Vice President
Technical Services
TigerAir, Inc.

DR. JOHN G. STEWART
Vice President
Resource Development
Tennessee Valley Authority

MR. MELVIN STONE
Aerospace Consultant
Former Director of Structures
Douglas Aircraft Comopany

DR. RICHARD A. VOLZ
Chairman, Department of
Computer Sciences
Texas A&M University

CONSULTANTS

MR. RICHARD D. BLOMBERG
President
Dunlap and Associates

MR. I. GRANT HEDRICK
Senior Management Consultant
Grumman Corporation

DR. SEYMOUR C. HIMMEL
Aerospace Consultant, Former
Associate Director, NASA LeRC

DR. WALTER C. WILLIAMS
Aerospace Consultant
Former Consultant to
NASA Administrator

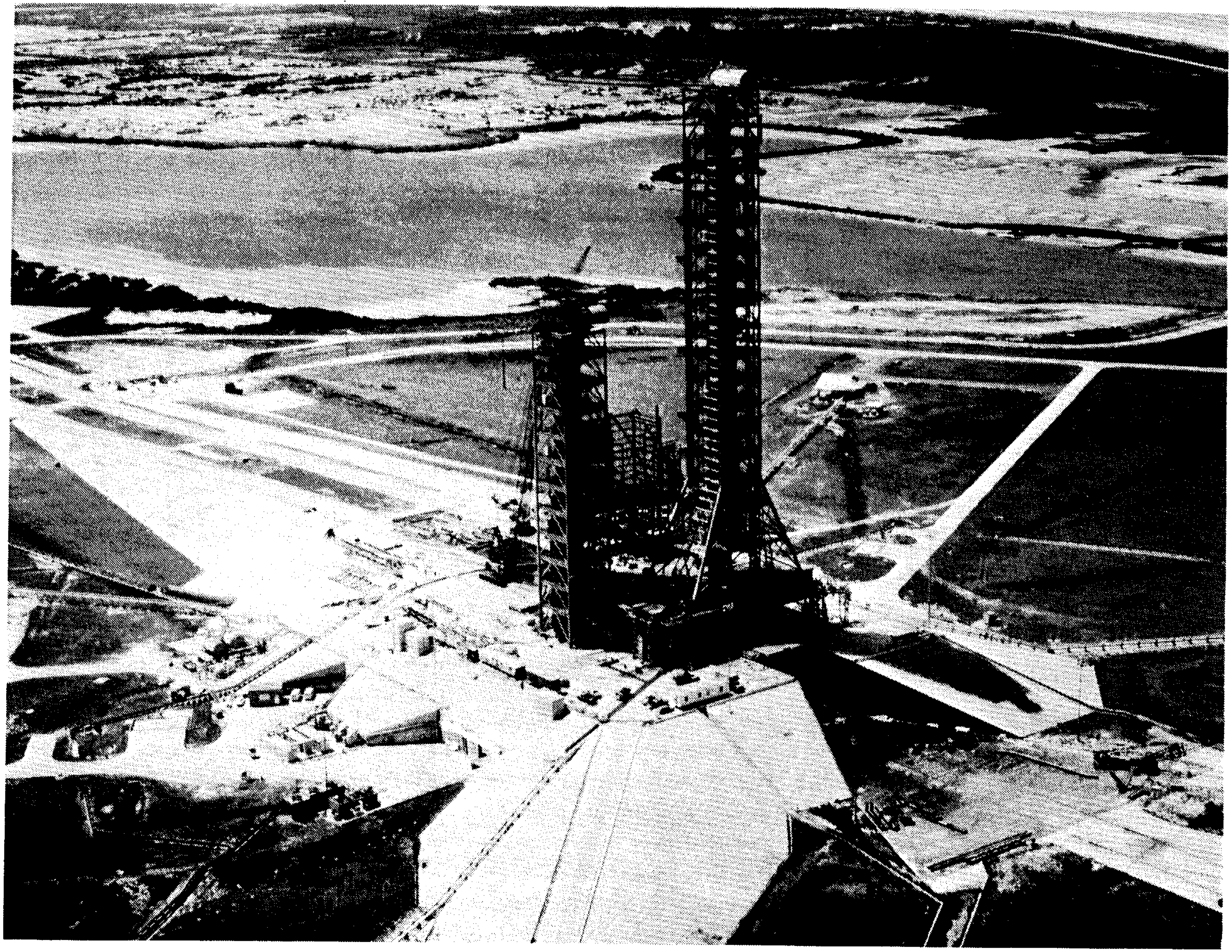
EX-OFFICIO MEMBER

MR. GEORGE A. RODNEY
Associate Administrator for Safety,
Reliability, Maintainability and Quality
Assurance, NASA Headquarters

STAFF

MR. GILBERT L. ROTH
Staff Director

MS. PATRICIA M. HARMAN
Staff Assistant



B. NASA RESPONSE TO MARCH 1989 ANNUAL REPORT

SUMMARY

In accordance with the Panel's letter of transmittal, NASA's response dated June 26, 1989, covered the "Findings and Recommendations," as well as the "open" items from prior annual reports.

Of those items which were "open" from the 1988 annual report, the above NASA response closed all but three which have been repeated in a similar form in both the 1989 report and in this report. They are:

1. Orbiter OV-102 strain gage calibration (page 41, C.3.a.).
2. Crew emergency rescue vehicle activities (page 47, D.2).
3. Aircraft operations and safety management (page 49, E.4).

Of the 34 findings and recommendations from the March 1989 report, the Panel considers 20 of them closed and 14 open. The open items are:

Number	Page	Subject
A.4	10	Space Shuttle Logistics and Support
A.5.a.(1)	12	Solid Rocket Motor/Booster Redesigned Solid Rocket Motor
A.5.a.(2)	14	Solid Rocket Booster Aft Skirt Structural Strength
A.5.c.(1)	16	Negative margins of safety, orbiter, reduction in flight envelope
A.5.d.	18	Space Shuttle Main Engine
A.5.e.	19	Launch, Landing and Mission Operations
B.1.a.	20	Space Station Management Structure
B.1.b.	21	Space Station semantics and commonly accepted definitions
B.1.d.	22	Space Station design interfaces and interface responsibility
B.2.a.	22	Assure resources are applied to SRM&QA are appropriate.
B.3.a.	24	A single purpose crew rescue vehicle

Number	Page	Subject
B.3.b.	24	Status of the Space Station caution and warning system
B.3.f.	26	Provisions for cleanup of toxic spills
D.a.	28	Risk management policies and implementation

NASA
National Aeronautics and
Space Administration
Washington, D.C.
20546
Office of the Administrator

JUN 26 1989

Mr. Joseph F. Sutter
Chairman
Aerospace Safety Advisory Panel
9311 Fauntleroy Way
Seattle, WA 98131

Dear ~~Mr. Sutter~~ Joe–:

In accordance with your introductory letter to the Aerospace Safety Advisory Panel (ASAP) Annual Report dated March 1989, enclosed is NASA's detailed response to Section II, "Findings and Recommendations" and the "Open" items noted in Section IV.B, "NASA Response to Panel Annual Report, March 1988."

The ASAP has again proven its excellence and viability. Your recommendations play an important role in risk reduction in NASA-wide manned and unmanned programs and projects.

We thank you for your valuable contribution and look forward to your comments in your next report. As always, your recommendations are highly regarded and receive the full attention of our senior management personnel.

Sincerely,

Richard H. Truly
Acting Administrator

Enclosure

Joe, thank you for the dedication to helping NASA shown by you and all the ASAP. I look forward to continuing to work with you.

Dick

II FINDINGS AND RECOMMENDATIONS

A. NATIONAL SPACE TRANSPORTATION SYSTEM

1. Management Structure

a. **Finding**: *Strengthening the role of NASA Headquarters (Level I) and STS program management (Level II), coupled with tighter management and budgetary controls over NASA's R&D Centers (Level III), has clarified responsibilities within the total STS program and strengthened authority and accountability at all levels. Of special importance is the position of Deputy Director (NSTS) for Operations as the focal point of the highly complex shuttle processing and launch activities at the Kennedy Space Center.*

Recommendation: It is essential that this more disciplined management structure - characterized by clear lines of authority, responsibility and accountability - continue in place once the launch rate accelerates in order to support NASA's commitment to the operating principle of "Safety first; schedule second."

NASA Response: NASA agrees. The Space Transportation System (STS) management system is reviewed on a continuing basis to ensure that established clear lines of authority, responsibility, and accountability are effectively entrenched to accommodate planned accelerated launch rates. The Management Councils involving the NASA Manned Space Flight Center Directors and the monthly General Management Status Reviews serve to enhance NASA visibility within the STS program and provide assurance of management strengthened authority and accountability at all levels. Primary emphasis continues to be placed on preventing communication breakdown and ensuring that vital information pertinent to the decision-making process is provided to appropriate levels of management in near real-time.

In addition, the Deputy Associate Administrator for Systems Assurance, Code QA, is developing an audit/survey process that will be used to assess the acceptability and responsiveness of the SRM&QA efforts in each NASA program, including the National Space Transportation System (NSTS) program. One of the major purposes of this audit/survey process will be to further ensure that clear, effective, efficient lines of authority, responsibility, and accountability are established and remain in place. Efforts to date have concentrated on: analyzing existing policy documents and their flow throughout NASA; and developing a generic, model survey plan that will be the blueprint for conducting a survey of NSTS Level 2 and Level 3 during the first quarter of FY 1990.

NASA has no intention of letting the strengthened Level I, II, and III roles degrade. The operating principle of "Safety First, Schedule Second" will continue as NASA policy.

b. **Finding**: *The Safety, Reliability, Maintainability and Quality Assurance (SRM&QA) function is now stronger, more visible, better staffed and better funded since establishment of the position of the Office of Associate*

Administrator for SRM&QA which reports directly to the Administrator. The Panel notes that the incumbent, George Rodney, is a part of the key decision loops and has established the beginnings of an essentially independent "certification" process within NASA. However, there is recent evidence that budgetary pressures within the Shuttle program are causing project directors to propose budget cuts in various SRM&QA activities (e.g., safety documentation associated with the Space Shuttle Main Engine, such as FMEA/CILs and Hazard Analyses, and oversight of major STS projects).

Recommendation: Across-the-board budget cuts that jeopardize the recently strengthened SRM&QA function must be denied. Funding to maintain essential safety-related documentation of STS systems must be provided.

NASA Response: NASA agrees that problems such as funding cuts that jeopardize the continuing strengthening of the SRM&QA function must be resolved. Across-the-board budget cuts not only have a debasing effect on Safety, but on all areas of NASA. Management realizes that it is necessary to look at the overall NASA program to evaluate the best and most efficient way to administer resources.

In several areas, prior major efforts have reduced the outstanding work load so that available resources can be channeled elsewhere for best overall results relating to Safety. For example, in the area of Failure Modes and Effects Analysis/Critical Items Lists (FMEA/CILs) and hazard analyses, a major rebaselining of all hazards was undertaken during the hiatus after STS-51L. The rebaselining effort has been completed; hazard and FMEA/CIL evaluations are now needed only when new hazards are discovered or when configuration changes and new development designs are initiated. This is a considerably smaller effort than during the rebaselining effort, where all existing hazards were revisited and reevaluated. While the hazard FMEA/CIL process is and will continue to be proactive, the quantity of analyses will vary based on design changes to the systems, the elements being deployed, and those hazards that are discovered during operation/evaluation periods. Resolution and documentation of problems associated with hazard analyses and FMEA/CIL findings will continue. However, the backlog of problems and, therefore, the effort is decreasing as problems are resolved.

To help identify common funding problems within the Safety community, Headquarters Safety Division, Code QS, convenes a Quarterly Center Safety Directors Meeting. This meeting allows the Safety Community to air safety issues that require additional funding and/or personnel. In addition, the Associate Administrator for SRM&QA periodically meets with the SRM&QA Directors from the nine NASA Centers. The agenda at these sessions permits open discussion of problems and issues, such as problems created by funding cuts and reallocation of resources. With the insight acquired through this forum, the problems can be addressed at the Headquarters level, and appropriate action can be initiated with cognizant program managers. This facilitates the resolution of impacts created by funding problems and maintains the vitality of a healthy NASA-wide Safety program.

c. **Finding**: *Management communications, a necessary component in achieving a successful STS program, have improved, both horizontally and vertically within NASA. In particular, the reinstatement of the Management Council, an entity that fosters direct and regular communication among all top STS managers and center directors, has brought a higher level of awareness of common problems and coordinated action to resolve them. This, in turn, has resulted in better informed and effective design certification reviews (DCRs) and flight readiness reviews (FRRs).*

Recommendation: As the flight rate increases, greater attention to maintaining these improved communication channels will be required.

NASA Response: NASA agrees with the need to maintain the improved and strengthened management communications channels. NASA fully intends to maintain the higher level of awareness that now exists in the Space Transportation System (STS) program management structure. NASA also plans to continue the Management Council to foster direct and regular communication, and to ensure better informed and effective assessment of STS program concerns and actions as the flight rate increases.

d. **Finding**: *NASA, along with many other Federal agencies, has suffered through more than a decade of hostility directed toward Federal employees and a related failure to maintain salary comparability at the higher management levels. NASA urgently needs greater flexibility and resources in competing for and retaining the skilled personnel who are required to carry forward the Nation's space and aeronautical programs.*

Recommendation: Although the salary comparability question will be settled by the Administration and Congress, NASA should speak out clearly about the increasing costs of the present situation and the specific steps that are needed to once again make NASA careers among the most desirable and respected. (P. 2)

NASA Response: NASA agrees that specific steps are needed to make NASA careers among the most desirable and respected. This has been a priority issue within NASA, and various approaches have been implemented to raise and maintain the professional stature of NASA personnel. However, the monetary reward and/or pay structure are legislated external to the Agency. Competing with industry for top talent, especially in high cost of living areas, is a serious problem.

Within the Agency, various career development programs that permit career growth have been implemented. Also, job flexibility programs permit personnel to change positions and jobs horizontally within the Agency, as well as vertically, to gain varied background and experiences. This approach provides new and interesting personal challenges and, at the same time, promotes interest and growth.

Training and recruitment programs at both professional and nonprofessional levels also continue as a top priority at NASA Headquarters and the Centers.

The NASA Quality and Productivity Improvement Programs Office has as a primary responsibility, the function of finding better ways to stimulate productivity and providing methods and programs for rewarding professional achievement. Recognition for performance is an important factor in retaining the skilled work force.

In summary, there is a problem in attracting and keeping professional personnel. The salary base commensurate with responsibility, which is legislated external to the Agency, as well as the uncertainty of funding for existing and new space programs have made attracting and keeping top-level managers and engineers a serious problem. This is an Administration and Congressional issue.

2. Safety Enhancements

a. **Finding**: *To ascertain the nature of efforts to enhance the safety of the NSTS through upgrading of the five elements (Orbiter, External Tank, Solid Rocket Motor/Booster, Space Shuttle Main Engines, and the Launch and Landing process System) the ASAP requested compilations of such improvements from both NASA centers and their prime contractors. These lists are shown in Appendix IV.D. which only cover currently recommended changes for reliability and flight and ground safety beyond those installed for STS-26. Other such changes may reveal themselves as the program progresses.*

Recommendation: These lists, and other changes as they are identified, should be prioritized based on attributes of safety enhancement (severity and consequence), cost, schedule and performance. This prioritizing should use the data bank developed as a result of the post-Challenger reviews and the results of the missions from STS-26 and on. Advantage should be taken of risk analysis techniques.

NASA Response: NASA agrees with this recommendation, and effort has been expended in the development of a list of improvements that should be made to improve the reliability and safety of the NSTS. The list was compiled utilizing data from risk analyses that have been already performed and trend analysis techniques based on actual failure history, evaluations of the waiver history, maintenance records, logistics records, modification and change data, as well as operation procedures and test data. Margins of safety and design specifications have been reviewed as well as analysis of FMEA/CILs for consideration of safety hazards.

In many cases, the areas of concern are clearly visible; however, providing the safety enhancements is a complex task. Many factors are involved, and extreme care has to be taken to make sure that new hazards are not created during attempts to modify or replace systems. Enhancements in some areas would require development in advanced technology areas where verification of producibility is not certain. Analyses in such areas are underway, and tradeoffs are being made relative to technology required which consider viability relative to time for development and qualification, impacts to other elements of the STS, and associated cost.

In summary, Code M and Code Q have spent considerable effort and will continue to do so in the development of a prioritized list where reliability and safety enhancements should be made. Analyses are ongoing to make sure NASA understands the complexities and technical risk involved relative to all proposed changes. The funding for changes is a major factor, and the cost must be thoroughly understood prior to proposing and approving any modifications. NASA is progressing in the direction proposed by the ASAP recommendation. Effort will continue to reduce risks in both flight and ground operations.

3. Advanced Solid Rocket Motor (ASRM)

a. Finding: *NASA's decision to procure the Advanced Solid Rocket Motor (ASRM) is based on the premise that the new motor will benefit from advanced solid rocket motor technology and new manufacturing methods and thus would evolve into a safer and more reliable motor than the current redesigned solid rocket motor (RSRM).*

On the basis of safety and reliability alone it is questionable whether the ASRM would be superior to the RSRM which has undergone extensive design changes until the ASRM has a similar background of testing and flight experience. This may take as long as 10 years from go-ahead. In the interim, the current design is expected to have had over 160 additional firings prior to the introduction of the ASRM.

Furthermore, it is not evident why the new manufacturing processes planned for the ASRM cannot be applied to the manufacture and assembly of the RSRM. Consequently, it is not clear to the ASAP why NASA is proceeding with its plan to develop a new and expensive solid rocket motor, especially as there are still many elements of the STS system which, if modified or replaced, would add significantly to the safety of the operation. Furthermore, NASA has not thoroughly evaluated other alternative choices to the ASRM such as liquid rocket boosters.

Recommendation: The ASAP recommends that NASA review its decision to procure the Advanced Solid Rocket Motor and postpone any action until other alternatives, including consideration of long range objectives for future launch requirements have been thoroughly evaluated.

NASA Response: The NASA decision to procure the ASRM was made after thorough review of the major factors involved, including an assessment of potential alternative courses of action. Several of the more significant considerations that lead to the NASA decision to proceed with the ASRM Program are discussed below.

There have been major improvements in the National Space Transportation System (NSTS) as a whole, and in the RSRM in particular, since the STS-51L accident. RSRM joint integrity is much improved, and the degree of field joint and nozzle-to-case joint rotation during motor ignition has been reduced significantly. However, O-ring expansion is still required to preclude hot gas leakage. [The ASAP report (page 4) notes the need to develop a resilient O-ring material for primary and secondary seals to eliminate the required

(RSRM) field joint heaters.] The RSRM factory joints do not meet the redundant, verifiable seal design criterion, due to joint rotation. Every feasible precaution, short of complete redesign, has been taken to ensure that all RSRM joints will function as intended, and NASA has high confidence in RSRM joint integrity. However, the RSRM joint designs are not the best concepts now available, and are not optimally tolerant of off-nominal conditions or unanticipated combinations of events. RSRM joint integrity thus remains a concern for the long term.

The Advanced Solid Rocket Motor (ASRM) provides a positive solution to joint integrity by incorporation of welded factory joints and mechanical field joints that close upon motor pressurization. The mechanical joint closure criterion applies to all joints (igniter to case, segment to segment, and nozzle to case). The redesign of joints to use face seals rather than bore seals minimizes assembly damage potential and permits visual seal inspection until the final mating. Joint heaters, and their attendant failure modes, are eliminated. Furthermore, it is anticipated that insulation design improvements will further reduce potential debonds and/or leakage paths.

Another ASRM design criterion leads to obviation of the Space Shuttle Main Engine (SSME) "throttle bucket" during the maximum dynamic pressure regime with the attendant elimination or reduction of about 175 Criticality 1/1R failure modes for the STS. Information gained from actual flight experience has been shown that the safety factors for water impact loads, internal insulation, and nozzle erosion on the current motors are lower than the original design criteria; these deficiencies are to be rectified in the ASRM. Due to ASRM design innovations, it is anticipated that, relative to the RSRM, Criticality 1 failure modes will be reduced by approximately 30 percent, failure causes will be reduced by approximately 25 percent, and failure points will be reduced by approximately 30 percent.

Flight reliability is as dependent upon the method of manufacturing as it is upon design. The current motor manufacturing is highly labor intensive, and historical contractor data indicate that 40 to 50 percent of the encountered defects are workmanship faults. Furthermore, workmanship faults are prevalent in the entire family of solid rocket motor (SRM) failures. These findings led to the conclusion that ASRM should be designed for the prudent automation of manufacturing processes to minimize defects and maximize reproducibility. Short of a major redesign, which would be tantamount to a noncompetitive ASRM procurement, the RSRM will never achieve the aforementioned flight safety and reliability enhancements. Moreover, the ASRM significantly enhances industrial, environmental, and public safety.

The ASRM will eliminate all asbestos-bearing insulation and other material applications in favor of equally effective materials that are noncarcinogenic. The manufacturing automation will minimize the exposure of the work force to hazardous operations; and the new production and test facilities will incorporate features for environmental protection in anticipation of ever increasing stringency in environmental constraints.

In consideration of public safety, we believe that for the long term, water transportation is preferable to rail transportation. Over the past 10 years, there have been 20 railroad incidents wherein SRM rail cars have been damaged. Fortunately, only 4 of these incidents occurred with live motor segments on the cars, and none damaged the motors. With time, railroad right-of-ways will likely become more congested and public exposure will increase. The availability of water, as well as rail, transportation was a significant consideration in the selection of the preferred ASRM production and test facilities. While barge accidents occur, the consequences of a rail accident could be more severe.

In addition to the aforementioned safety and reliability features of the ASRM, there are policy, programmatic, and procurement considerations that are very important. Starting as early as 1984, NASA began exploring the prudency of recompeting the SRM contract. The STS-51L accident led to more detailed technical and programmatic considerations, which culminated in a report to Congress in March 1987, outlining three options:

- Continue the RSRM contract as a sole source.
- Recompete the RSRM contract.
- Pursue an ASRM through competition.

The Agency and the Congress mutually elected to pursue ASRM to achieve both technical and programmatic benefits, to vitalize the solid motor industrial base, and to provide a realistic competitive environment. Those rationale are as pertinent today (if not more so) as they were in 1987. Through design, production, and operational features, the ASRM will provide enhanced safety and reliability at reduced cost, and enable the Government to recompete the program in the future.

The post STS-51L NSTS redesign activity has eroded an already under-performance Shuttle payload capability. The ASRM is expected to provide a 12,000-pound payload improvement and restore the Shuttle to its full design capability, a factor of no small importance considering the payload backlog, mission model delays, and the increasing mass of deployed payloads such as Space Station.

The need for modern production facilities is no less important than the need for solid motor design improvements. The solid motor industry, by and large, has been slow to modernize manufacturing techniques and facilities, and is characteristically labor-intensive. The ASRM procurement has triggered an industry-wide reevaluation of producibility and productivity. The introduction of automation should greatly enhance the reproducibility from motor to motor. Currently, right- and left-hand booster segments are "match cast" and maintained as pairs throughout their life. This is expensive and has resulted in destacking of both boosters because of a problem in one segment. Destacking and restacking also bring the potential of new problems. The ASRM automation is the only prospect on the horizon of departing from the current practice of "matched casting."

NASA has concluded, reinforced by the findings of the five solid motor contractors, that the extent of modernization required for manned flight safety and cost effectivity support a new, optimized facility rather than the modification and disruption of existing plants. This seems to be borne out by the fact that modernization proposals by the RSRM contractor are comparable to the construction cost estimates for a completely new ASRM production and test facility. Furthermore, once the Government invests in the modernization of a contractor's facility, it must be recognized that it would be prohibitively expensive to so equip another contractor(s) and any benefits of recompetition would be forfeited.

NASA, with industry support, has aggressively studied liquid rocket boosters, and has concluded that the technology is a long way from implementation. An obvious attraction of liquid rocket boosters is the prospect of more flexibility in abort modes. However, since the other Shuttle elements were never designed for abort loads, the effectiveness of liquid boosters might be limited due to the necessity to operate within the constraints of those designs. Also, there are other significant implications of a change to liquid rocket boosters for the Shuttle, necessitating extensive changes to the STS and the supporting assembly and launch facilities, and extensive wind tunnel testing and analyses to recertify the STS.

With regard to postponement of the ASRM procurement, Public Law 100-147-Oct. 30, 1987 (Section 121(d)) provides that failure to complete the ASRM procurement requires:

- Competition to select a qualified second source for RSRM, or

- Recompetition of the current RSRM contract.

Since there is only one facility in the country for building the RSRM, any meaningful competition would necessitate the Government making provision, in a nondiscriminatory way, for prospective competitors to acquire a new facility. Furthermore, to entertain the expense of such a competitive procurement and not incorporate provisions for rectifying deficiencies in the existing motor and/or improvements would be imprudent. Hence, one returns to the ASRM as the sound programmatic decision. The validity of this decision is reinforced by the fact that the extent of design and processing changes envisioned for the ASRM constitute, by law, "significant new procurement." To evolve the current RSRM to an ASRM would, most likely, place NASA in noncompliance with the Competition in Contracting Act.

NASA considers the ASRM to be a soundly conceived, well-considered program that will result in significantly improved safety and reliability; provide an extremely important improvement in STS performance; minimize life-cycle costs; enhance the viability of the SRM industry; and enable the government to be in a position to recompete the program in the future. The alternatives have been considered, and the ASRM is clearly the best approach available. NASA plans to proceed with the ASRM.

4. Logistics and Support

Finding: *A review of the development of the overall logistics and support systems for the STS shows a very satisfactory trend. Full advantage has been taken of the "stand-down time" resulting from the STS-51L accident. Especially noteworthy is the movement of key Rockwell personnel to the KSC area and the enhancement of direct control of the logistics program right up to the launch pad itself. The NASA-KSC logistics organization has made great strides in facilities, equipment and inventory and has been aided immeasurably in this task by protection against having its funds occasionally diverted to other STS areas, as was the case in earlier years. There appears now to be excellent liaison between top management of NASA-KSC and Rockwell-Downey and a real spirit of co-operation is observable at this level which has permeated down to the ranks.*

There are, however, areas still in need of attention: (1) the control of all STS logistics is not centralized at KSC, (2) the repair pipeline turnaround time is much too long to support the program.

Recommendation: Continue the good work. Focus efforts on the need to improve overhaul and repair turnaround time, and the integration of all STS logistics programs in one place - KSC.

NASA Response: The National Space Transportation System (NSTS) logistics program is strongly supporting the NSTS mission. The Kennedy Space Center (KSC) is currently meeting a 99 percentile fill rate for nonrepairables and 90 percentile fill rate for repairable assets. The Orbiter hardware composite fill rate for both repairables and nonrepairables is 98 percentile against a fill rate goal of 90 percentile. The fill rates for Orbiter flight hardware have been improved by both an increase in the range (number of items stocked) and depth (quantity of items stocked) of spare assets at KSC, along with a maximum focus being placed on reducing manufacturing and repair turnaround time. Attendant with these actions has been a major emphasis on transitioning both manufacturing and repair activities to the KSC Shuttle Depot (Rockwell Service Center) located in close proximity to KSC where such actions are technically and economically viable. Further actions have been taken to improve the procurement time for long lead assets and to incentivize contracts for improved repair turnaround time at original equipment manufacturers (OEMs) where transition to the RSC is not viable.

An additional factor in influencing the Orbiter repairable asset fill rate is the ongoing asset modification program. Typically, spare assets are removed from service first for modification and later returned to inventory to support vehicle operations. Thus, the modification program also contributes to reduced fill rates.

As noted in the finding, the repair pipeline turnaround time remains much too long to support the program at the higher launch rates. To resolve this problem, an increase in the stock levels of selected spares has been initiated to compensate for repairable items in the process of undergoing maintenance, either in work or awaiting work. In addition, KSC has a continuing and ongoing program to reduce repair turnaround time to acceptable levels. The key and essential element to this turnaround time reduction is the centralization of repair at the local depot, and numerous actions are underway to achieve this objective.

The increase in range and depth of spares, along with the actions taken to reduce repair turnaround time at the OEMs and through the optimum use of the KSC depot, coupled with the eventual completion of Orbiter Line Replaceable Unit (LRU) modification, are expected to improve fill rates to meet or exceed program goals and, accordingly, provide the required level of logistics support at the higher flight rates.

With regard to the finding that control of all Space Transportation System (STS) logistics functions have not been centralized at KSC, NSTS policy is being revised to include a logistics management responsibility transfer agreement between the design centers and KSC that will result in a schedule for transfer of logistics responsibility to KSC. The Orbiter logistics program, which was transitioned to KSC in 1986, is being supported by a very sound structure that includes KSC Logistics Management; Rockwell International; and Lockheed, the Shuttle Processing Contractor (SPC). Thus, the transition of elements to KSC has been successfully demonstrated. It is the intent of the NSTS program to achieve total STS logistic program integration via transfer of the remaining logistic support programs to KSC. This action will require a program-level review and evaluation of the programs impacted to assure program continuity. All viable logistics management functions will be transferred to KSC with the exception of the responsibility for support of technological opportunities and improvement programs that result in engineering changes. The transfer agreements are tentatively scheduled to be completed in December 1989.

5. Space Shuttle Elements

a. Solid Rocket Motor/Booster (SRM/SRB)

(1) <u>Finding</u>: *The redesigned solid rocket booster is more reliable than those used through the STS-51L mission. A number of significant areas of continuing concern were identified during redesign and testing of the new booster: These included the following:*

(a) the need to eliminate possible voids and blow holes in the polysulfide adhesively bonded case-to-nozzle joint;

(b) a better characterization of the materials used in the internal nozzle ablative composite parts;

(c) the need to prevent the accumulation of slag, which plugs cowl vent holes during tail-off burning, resulting in adverse differential pressure across the nozzle flexible boot;

(d) the need to develop a resilient O-ring material (temperature compatible) for primary and secondary seals in order to eliminate the required field joint heaters; and

(e) the need to conduct a structural analysis in order to determine the criteria for safe reuse of rocket motor case segments.

Recommendation: NASA should develop a program based upon the items listed above and other significant items to improve the solid rocket motors/boosters and further reduce risk.

NASA Response: The Redesigned Solid Rocket Motor (RSRM) Project is developing and evaluating a Product Improvement Program utilizing a block change concept. The justification for the majority of the proposed improvements is enhancement of Safety, Reliability, and Quality Assurance. With respect to the specific five areas of concern listed by the ASAP, the following status is provided:

(a) Blowholes in the polysulfide used to bond the insulation at the RSRM nozzle-to-case joint have been virtually eliminated by improving the processing and assembly techniques in this area. Post-flight inspections of the joints on the first three flight sets (six motors) showed no blowholes. Included in these improvements were controlled rate of assembly to give trapped air time to bleed-off through the vent slots and controlled temperature at assembly to assure proper viscosity of the polysulfide. Action is currently underway to evaluate pulling a vacuum through the vent port during assembly to further expedite the bleed-off of trapped air. Also under evaluation is a metered mixer for the polysulfide that will provide a mix free of entrapped air. A second benefit of the metered mix is that the two-part polysulfide is not mixed until immediately prior to application. This allows for use of freshly mixed adhesive and minimizes the possibility of violating polysulfide pot life. While these changes are being evaluated to possibly improve the design, the need to change is not currently judged a necessity. First, the probability of blowholes has been shown to be very low; second, the effects of a blowhole have been demonstrated via flaw testing of simulators and of a full-scale, full-duration motor firing to be inconsequential.

(b) Activity in this area is underway. The Marshall Space Flight Center (MSFC) Materials and Processes (M&P) laboratory, along with MTI, are conducting a program to better characterize the carbon cloth phenolic (CCP) that is used as an ablative material in the RSRM nozzles as well as in many other applications outside the RSRM program. A Nozzle Technology Program is also underway to investigate the effects process variables have on the ablative performance of CCP. A CCP Data Base Program has been started to gather data on CCP from numerous sources. MTI has implemented many improvements in the manufacturing processes and, as a result, the defect level has been substantially reduced. The internal nozzle parts from the first three flights and static test motors QM-6, QM-7, PVM-1, and QM-8 (10 successive motors) have shown no anomalous conditions.

(c) MTI has a nozzle cowl vent hole test program in progress utilizing the technical evaluation motors (TEMs). This test program is attempting to define a vent hole configuration that will resist slag accumulation and resulting adverse differential pressure build-up in the boot cavity area of the nozzle, yet not introduce other adverse effects such as heat damage to the flex bearing or its protective cover. One test (TEM-02) has already been conducted that included enlarged vent holes, erodible plugs in standard size vent holes, and Teflon-sleeved vent holes.

(d) During the RSRM redesign, tests were conducted on many different O-ring materials to determine which material would best meet all field joint seal requirements. Despite the necessity to maintain O-ring temperature above 75 degrees Fahrenheit at RSRM ignition, the fluorocarbon material best met all requirements, including resiliency, sealing performance, producibility, compatibility with established lubricants and overall toughness. Subsequent full-scale ground testing has completely confirmed acceptable sealing performance characteristics. Although flight experience to date--due to the total effectiveness of upstream sealing redundancies--has not directly challenged O-ring sealing capabilities, all flight data measurements tend to confirm adequate seal designs. Therefore, there is currently no active program to develop a new elastomer, or other type seal, that would provide adequate overall dynamic response for temperature requirements below 75 degrees Fahrenheit. Design enhancements are being evaluated to include a proposal to develop and implement an improved RSRM O-ring material to eliminate the requirement for field joint heaters.

(e) The criteria for safe reuse of a case segment is established. Each segment is subjected to a hydroproof test of 1.12 times the maximum expected operating pressure and then undergoes nondestructive evaluation to certify that it is acceptable for the next reuse. However, completing an analysis to verify that the case segments are capable of 19 reuses is a different and very complex matter, and is currently being addressed by both MTI and MSFC.

(2) **Finding**: *The booster aft skirt failed on STA-3 static structural test article at 128% of limit load. This is below the required factor of safety of 140% (1.4 over limit load).*

Recommendation: Perform tests to determine the effect of various loadings and provide fixes needed to meet the original design requirements.

NASA Response: The aft skirts are instrumented with 120 strain gages on each booster, some of which are located in the thrust post weld areas as on the STA-3, which allows a correlation of actual stresses during stacking and launch to the STA-3 test. The data have been recorded during the Flight Readiness Firing (FRF) and is currently in place for the first six launches. The Solid Rocket Booster (SRB) project is proposing six additional flights to gather the necessary data to support decisions on potential design changes. These strain gages are also used to measure the stresses induced in the welds during the booster stacking processes to assure that a minimum factor of safety (F.S.) of 1.28 is maintained. Reconstructed loads from the actual data from the first three flights have indicated a F.S. of about 1.36.

One approach being considered as a potential for improving the factor of safety is inducing a compressive preload into the critical welds by biasing the spherical bearing interface between the aft skirt and mobile launch platform during initial stacking operations. The compressive preload will increase the capability of the critical welds, which failed in the STA-3 test due to tensile stresses. A maximum bias was attempted during STS-30 buildup, but was aborted because of rotation of the aft skirt shoe. The project plans to further test this concept on the Transient Pressure Test Article (TPTA) at the Marshall Space Flight Center. The data gathered during stacking of the first three flights, and the aborted attempt indicate that a lower bias value probably will give the desired results. The full-scale TPTA hardware will be used to further develop this concept rather than risk flight hardware and flight schedule by attempting this during flight hardware buildup.

b. External Tank (ET)

Finding: *There have been numerous failures of various sensing devices for liquid levels, temperature and pressure on both the hydrogen and oxygen tank systems. Many of these measurements are used in launch commit criteria and are required during flight.*

Recommendation: NASA needs a coordinated effort to resolve the cause of these many sensor problems and should take the necessary actions to remedy this situation.

NASA Response: In general, the majority of the sensor and transducer failures occurred during acceptance testing procedures (ATPs) that have served the intended function of detecting failures before installation of the transducer in the External Tank (ET). Several of the failures have been isolated cases and have been caused by personnel error or improper testing procedures. However, most of the failures have been attributed to contamination during fabrication which is considered inherent to the manufacturing process. Therefore, failures of this type are considered to be a consequence of normal production fallout.

Most of the sensor/transducer problems have involved the liquid oxygen (LO_2) and liquid hydrogen (LH_2) ullage pressure transducers. The typical failures have been cases where the transducer exhibited erroneous readings, high contact resistance/signal dropout, or electrical noise. These failures occur most often during vendor ATP, with contamination of the transducer internal mechanism identified as the probable cause. Although the contamination is considered inherent to the manufacturing process and these occasional failures have been considered to be normal production fallout, additional inspection requirements have been added to the fabrication process. The transducers must pass ATP at the vendor to ensure that there are no defects at the time of delivery. Operational/functional testing of the transducers is performed when the transducers are installed at the ET assembly facility. Procedures at the launch site require verification that the transducers are operating properly. There are four LH_2 ullage pressure transducers (three are used in flight, and one is a spare). Switchout of a failed transducer with the spare can be accomplished throughout propellant loading up to T-10 seconds. A similar switchout also can be performed for the four LO_2 ullage pressure transducers. A different type of ullage pressure transducer that eliminates the contamination and resistance contact problems is currently in qualification testing. This transducer will eliminate the failure modes experienced by the present transducer design, and is expected to be qualified by late 1989.

Failure of the ATP resistance test has been the most frequent problem reported on the LH_2 and LO_2 level sensors. Again, these failures are expected as a natural result of the sensor design and production process, and any sensor failing ATP would not be a candidate for ET installation. To reduce the number of ATP failures, numerous process changes and additional inspection requirements have been implemented. Of the 680 liquid-level sensor systems that have flown, only 4 have failed. Three of the four hydrogen depletion sensors would have to fail "wet" simultaneously to cause SSME failure. Frequency of temperature sensor failures has been much lower than those encountered on other ET sensors/transducers and these sensors are not used as control indicators during flight.

A program is being planned that will assess NASA's current capability in providing reliable instrumentation. Given the numerous failures in this area (most occurring during ATP), a recommendation is under serious consideration to establish a central expert instrumentation group that would develop all of NASA's sensor hardware.

c. Orbiter

(1) **Finding**: *Upon completion of the 6.0 loads/stress analysis it was determined that negative margins of safety existed in the Orbiter structure. In order to launch STS-26 and subsequent missions, it was necessary to reduce the design flight envelope to such an extent that the probability of launch was considerably below the original target of 95%.*

Recommendation: If NASA desires to attain the originally specified high probability of launch they should implement the identified structural modifications (structural area of the wings, fuselage and vertical tail).

NASA Response: The allowable flight envelope was revised at the Design Certification Review in March 1988; that certification was derived from 6.0 loads/stress analysis. The scope of the analysis used in certification included 60,000 structural components and 30 major structural elements including the wing, vertical tail, and mid-fuselage. Further analysis results indicate that the majority of the orbiter structure has positive safety margins and constraints have been defined for critical structures (wings, tails, aft fuselage, OMS pods, and wings leading edge) to ensure positive safety margins. Since launch probability can degrade due to constrained structure, structural modifications are being made as program requirements dictate.

Currently, NASA is assessing their latest structural analysis and identifying load cases that should be replaced with more realistic loads data. The Space Shuttle Columbia (OV-102) was instrumented on previous flights to collect wing pressure distributions. These instrumented flights will continue to improve the data base used to certify the math models used for wing load prediction. In addition, the Space Shuttle Atlantis (OV-104) is being instrumented with accelerometers on the tail and wing area to measure flutter and buffet loads that are experienced during Max Q. Upon completion of the STS-26 analysis update and subsequent instrumented flights, NASA will have a much better data base to reduce conservatism in predicted structural capability.

Major modifications have already been accomplished on all vehicles in the past particularly to improve the load-carrying capability of the wings. Future modifications, if required to improve margins of safety as a result of ongoing 6.0 loads analysis and new flight data, will involve more complex modifications and may require a major vehicle down period to accomplish. Completion of the design/analysis is expected toward the end of 1989.

(2) **Finding**: *The current General Purpose Computer (GPC) flying on the Orbiter is built upon very old, outdated technology and is a limiting factor in Shuttle operations (due to memory limitations, among other things). It will be increasingly difficult to maintain because parts for the older technology will become increasingly difficult to obtain. The GPC needs to be upgraded as soon as possible. NASA has been working on a replacement central processing unit for at least 5 years now, and use of the new processor is still not scheduled until 1990. The sooner that the upgrade is completed, the sooner advanced applications programs can be placed in the computer system.*

Though the new GPC has been tested extensively in the laboratory, there are no flight tests scheduled for the new processor.

Recommendation: NASA should plan at least one flight test with the new GPC's carried as a test payload and used throughout the flight in a test mode. The computers should be used in as close to an actual flight mode as possible, including sensor inputs if that can be done, except, however, that the new GPC's should not be in line with any actual control outputs. This test should be performed and the upgrade completed as soon as possible.

NASA Response: The new General Purpose Computer (GPC) is scheduled for first flight on STS-41 in October 1990. Design work for the new GPCs began in January 1984. Confidence and validation of the GPCs are being performed using special versions of software, Operational Increments 9A and 9B (OI-9A/9B). These tests will tentatively be completed by March 1990. The actual flight software (OI-8F) will be verified during the 5-month period from April to September 1990. Prior to April 1990, the new GPC will undergo 1,000 hours of burn-in, 200 hours of redundant set time, and 2,000 hours of quality set time. Installation of the new GPCs in the Space Shuttle Atlantis (OV-104) will begin in May 1990.

Because an extensive amount of flight data has been collected from previous missions, the new GPC can be placed in a test environment with a data flow that is identical to an actual flight environment. The processing speed of the new GPC is significantly faster than the old GPC. Therefore, to synchronize both GPC systems on an actual flight would be extremely difficult if not impossible. In addition to the software modifications needed to test both GPCs running in parallel, alteration of the Shuttle avionics bays and data bus wiring to accommodate both GPC systems would be required. Ground testing of the new GPCs is sufficient to ascertain performance and reliability characteristics and is certainly more cost-effective, considering the additional modifications that would have to be made to test both GPC systems in an actual flight mode.

d. Space Shuttle Main Engines (SSMEs)

Finding: *The engines used for the successful STS-26 flight incorporated 39 changes. Extensive certification testing was carried out on these changes with excellent success on all of the most critical items with the exception of the HPOTP bearings. The data indicates that the various cracking problems in the turbopump blades have been resolved. Limited testing on a large-diameter throat engine (0208) showed major reductions in various engine stress environments. A two-duct (versus current three-duct) hot gas manifold power head was completed and made ready for testing at year end. A complete structural audit, a detail assessment of all key welds on the engine, and a thorough failure trend analysis were also completed in 1988. Evaluation of a reliability model for the SSME was continued.*

Recommendation: The contractor should continue work to provide a high pressure oxygen turbopump (HPOTP) bearing having better margins to prevent failures due to wear and to provide longer cycle life. The two-duct power head and the large throat combustion chamber should be vigorously pursued and certified as rapidly as possible.

NASA Response: NASA fully concurs with the need to improve high pressure oxygen turbopump (HPOTP) design and is currently progressing down two paths to assure success. At Rocketdyne, the current pump (which is limited to a single flight per overhaul) is involved in the Block I Improvement targeted at pump and turbine end bearing improvements as well as jet ring modifications. These changes should allow 5,000 seconds (8 to 9 flights) between overhaul. The Block II improvements, which should yield a 7,500-second pump (13 to 14 flights), are targeted at the main impellar, turbine nozzle, and improved bearing wear. Concurrent with this activity is the alternate turbopump development effort at Pratt & Whitney. This HPOTP should see initial component testing in August 1989 and engine-level testing in January 1990. Since crystal blades are baselined for the alternate turbopump development program (Phase II+), NASA is targeting the first ground test on E-0209 in April 1989. Due to other program priorities and funding constraints, the two-duct development and certification testing has been deferred until FY 92/FY 93 with fleet implementation leading to a first flight in FY 95.

The large throat Main Combustion Chamber (MCC) is not currently baselined in SSME planning; however, E-0208, which is in test at Technology Test Bed (TTB), is configured with this feature. This engine will continue to be tested until September 1989 at which time the fully instrumented E-3001 will dominate TTB activity.

e. Launch, Landing, and Mission Operations

Finding: *As the flight schedule picks up in FY 1989, there remains the clear and present danger of slipping back into the operating environment at KSC that helped to contribute to the Challenger accident. At the same time, the need to achieve greater efficiency and cost effectiveness in turnaround procedures is clear. In this situation, NASA's commitment to the operating principle of "Safety first; schedule second" must be retained. If experience of the past is a guide to the future, the pressures to maintain or increase flight rate will be intense.*

Recommendation: NASA must resist the schedule pressures that can compromise safety during launch operations. This requires strong enforcement by NASA of the directives governing STS operations.

NASA Response: NASA and our contractors recognize the complex problem of increasing launch site efficiency while resisting schedule pressures that may compromise safety. Some of the specific actions that Kennedy Space Center has taken include: review of problems caused by human-induced error to ascertain whether additional training, job reassignment, or procedure change is required; and constant review of areas of high overtime/stress for schedule change and reassignment of personnel. In addition, NASA has established formalized training programs designed to reduce the potential for human error. The schedule and scheduling process are constantly reviewed and updated, as necessary, to ensure that all formal protocols are completed regardless of the affect on ability to launch on a specific date. NASA management from the top level through the first-line supervisor exercises constant vigilance to ensure that satisfactory working schedules and environments are maintained at all times in accordance with the operating principle, "Safety First, Schedule Second."

NASA continues to closely monitor workload imposed by the baselined STS flight rate. Manpower levels currently budgeted to support the STS flight schedule have been sized to assure that the processing workload can continue to be accomplished in a safe manner. Both staffing and overtime data continue to be reviewed by top management on a weekly basis to assure rigorous adherence to the overtime policy in Kennedy Management Instruction (KMI) 1700.2.

B. SPACE STATION FREEDOM PROGRAM (SSFP)

1. Management Structure

a. **Finding**: *The Space Station Freedom Program (SSFP) has an extremely complex organizational structure which includes a program support contractor (PSC) with system engineering and integration (SE&I) capability. NASA has not utilized this program support contractor effectively.*

Recommendation: NASA should ensure that the SSFP has a strong, competent systems engineering and integration team with the responsibility and authority to pull all of the various parts of the program together. (P. 6)

NASA Response: The Deputy Director, SSFP, has taken action to change the mission of the Program Support Contractor (PSC). Effective May 15, 1989, the principal emphasis of the PSC mission shall be to serve as the Space Station Freedom Integration Contractor. Accordingly, the title of Program Support Contractor is changed to Space Station Engineering and Integration Contractor (SSEIC). The principal tasks for the SSEIC in its role as Integration Contractor shall be restructured to be projectized or "turn-key," with a small proportion of level-of-effort support continuing to the NASA Level II Program Office for smaller, open-ended tasks. A Program Directive will be issued shortly describing the interface responsibilities of the SSEIC, the WP Contractors, and NASA Level III in program integration.

To fully implement the Integration Contractor role, a proposed SSEIC reorganization has been approved.

b. **Finding**: *There are semantic and definitional differences across the international partners and, perhaps, even the work packages. There is also an abundance of new acronyms being used. Some of these are a redefinition of acronyms used on previous NASA programs. As a result, there is great potential for confusion.*

Recommendation: NASA should ensure that there are commonly accepted definitions for key terms and acronyms. Where commonality is not possible, corresponding lists should be developed and widely disseminated. Continuing control over this process is required throughout the life of the SSFP.

NASA Response: The Space Station Freedom Program (SSFP) Program Requirements Document (PRD) and the Program Definition and Requirements Document (PDRD) control definitions and acronyms used on the program. Although this control currently is not being enforced, there is an active effort by NASA Headquarters to update, consolidate, and standardize the SSFP acronyms and abbreviations (JSC 30235, dated November 26, 1986). Implementation of this SSFP document will ensure the application of commonly accepted definitions for key terms and acronyms. The requirements of the SSFP PRD will be applied to new key terms and acronyms to ensure that they receive common definition for application throughout the SSFP.

c. **Finding**: *Some of the international partners have difficulty following discussions in English at the numerous working meetings. This limits their ability to make contributions and leads to the possibility of misunderstandings.*

Recommendation: Interpreters should be available at all meetings attended by international partners who have difficulty keeping pace with the English proceedings. The SSFP should make sure that it has ready access to document translators of sending and receiving meeting minutes, letters of clarification and project memoranda. (P. 6)

NASA Response: NASA agrees that communication and good understanding at all times with our international partners is essential to our development of the Space Station Freedom Program (SSFP). English is the common language on the program. At present, NASA does maintain ready access to document translators through our Translation Bureau (Mr. Len Wepasnick/202-755-1075), and written documents are translated on a contract basis. Primary responsibility for on-the-spot spoken interpretation rests with our international partners who are encouraged to provide representatives fluent in English. However, special requests by our international partners for interpretation can be accommodated with sufficient notice. The National Space Development Agency of Japan (NASDA) has solicited support from Hernandez Engineering, which has hired an interpreter/translator to provide language assistance.

d. **Finding**: *The number of interfaces, across which designs must be consistent, is very large. The responsibilities for defining design requirements to span these interfaces are not clear. This may lead, at best, to the need to backtrack in the design effort and, at worst, to the omission of a safety critical element.*

Recommendation: SSFP management should clearly define the interface responsibilities for design definition as soon as possible. This will help ensure that each item is addressed as the design work progresses because the cognizant center, work package or design office will be aware of its role in the definition. (P. 6)

NASA Response: The Space Station Freedom Program (SSFP) Office, Level II, is in the process of clearly stating the Level II design requirements as traceable, verifiable entities in Section 3 of the Program Definition and Requirements Document (PDRD). This will be the basis for a clear flow down of requirements to the Level III design activities. This will also form the basis for clearly identified interfaces between the various design activities. Also, Level II is defining all the detailed tasks that are to be done by Level II. These defined tasks will be assigned as engineering and integration activities to be accomplished by one of the following: (1) the Level II organization at Reston, (2) various NASA Centers under the guidance of the Space Station Integration Manager, and (3) the Program Support Contractor as an integration contractor.

2. Safety and Product Assurance

a. **Finding**: *The level of activity of the SR&QA program for the SSFP appears low considering the complexity of the system design, integration and operational problems. A human factors function is not evident in the program's organizational structure.*

Recommendation: Management should make sure that the resources applied to SR&QA activities are commensurate with the need. An identifiable human factors function at Level II should be established and should be tasked with key relevant issues. The SR&QA activity must maintain its independence of operation and not be subordinated within the program.

NASA Response: The key to an effective SR&QA program is proper organization and adequate staffing. Action has been taken to augment the staffing of the SSFP Safety and Product Assurance function. The authorized staffing level for FY 89 is 19 persons, as opposed to the authorization for 8 persons in FY 88. NASA Headquarters intends to maintain the SR&QA staffing level, which is approximately 5 percent of the engineering staffing. This ratio is derived from tested programs.

The Office of the Associate Administrator for SRM&QA, Code Q, has guaranteed the independence of the SR&QA activity on the SSFP by establishing a unique organizational support relationship with the Program Manager. This is the first time that this has been attempted in the Agency. While the program interfaces are still being worked out, the intent is to ensure that the SR&QA function does not get relegated to a lower tier.

The acceptance of human factors as a discipline is being promoted on the program as well as in NASA Headquarters. There has not been an Agency-level Human Engineering function to date. A draft NMI declaring that Code QS will become the Agency sponsor for the task is in the review process. Similar to the Reliability discipline, the engineering work will remain a System Engineering and Integration (SE&I) function; however, the Safety Division (Code QS) and the Space Station Safety and Product Assurance (Code SSQ) will provide oversight.

b. **Finding**: *The Safety Summit process started in February 1988 has shown the potential to make a marked improvement in the depth and breadth of the program's safety function. This process is being conducted despite the lack of a charger, which is needed to formalize its activity.*

Recommendation: The Safety Summit process should be made formal through approval of a charter specifically delineating its functions and responsibilities. (P. 6)

NASA Response: The Safety Working Group conducted by the Space Station Freedom Program (SSFP) Office is a periodic in-person meeting of the Senior System Review Panel that is formally established and organized by the provisions of paragraph 3.2 of the Space Station Level II System Safety Program Plan (DRAFT). The Senior Safety Review Panel is a SSFP-wide panel co-chaired by the Safety and Product Assurance Office, Code SSQ; Program System Engineering and Integration, Code SSE; and Program Utilization and Operations, Code SSU. This panel coordinates the resolution of important safety issues and problems. Biweekly, worldwide teleconferences by the panel are central to the ongoing coordination/assessment and evaluation/problem resolution process. The actions under study by this panel are thoroughly evaluated at the extended conferences called Safety Working Group meetings.

The Safety Panel has never been chartered, because the International Safety and Product Assurance Group (ISPOC) has never been chartered.

New direction on the SSFP has cut the number of panels and boards. However, the Program Director has directed SSFP personnel to use existing organizations and directives to accomplish the program requirements, and the Safety Working Group forum is still an active arm of the program.

3. **Technical Issues**

a. **Finding**: *The SSFP design as baselined still does not include a specific "lifeboat" or crew emergency rescue vehicle (CERV). It is not clear whether NASA has given up on providing this capability or still has the issue under study.*

Recommendation: The Panel has stated previously: "that a single purpose crew rescue vehicle or lifeboat should be an essential part of the Space Station's design."

NASA Response: A Change Request to Level I has been proposed by the Office of the Associate Administrator for SRM&QA, Code Q. The response to date has been to allow the Office of Space Flight, Code M, to define the requirements, and design and implement the system. Code M is scheduled to issue a request for proposal (RFP) for a study to define crew rescue methods during FY 89.

b. **Finding**: *The design philosophy for the caution and warning system (CWS) as embodied in NASA-STD-3000 does not provide sufficient guidance for establishing the precedence that the CWS should have in the design hierarchy. It also dictates a classification system which may not be best for the unique mission of the SSFP.*

Recommendation: The CWS system design should be given primary status among all SSFP signaling and information systems. (P. 7)

NASA Response: The Safety Working Group has been instrumental in initiating an action by Systems Engineering and Integration (SE&I) to establish a C&W "architect." At this time, JSC's DMS/Avionics organization has taken the lead in establishing this functional role. The scope of responsibilities for this "architect" has not been fully developed as yet, but they will include the following:

- Development and review of all C&W requirements at all levels of the program
- End-to-end architecture of the C&W system
- Oversight of the implementation of the C&W design
- Verification of the end-to-end system

Level II will ensure that this important responsibility is fully defined and implemented, and given primary status among all SSFP signaling and information systems.

c. **Finding**: *The Software Support Environment (SSE) being developed as the Station's primary software development tool appears excellent. It does, however, lack a provision for making safety checks of software as it is being developed. The SSE design process also does not include an independent validation and verification (IV&V) of the SSE itself.*

Recommendation: The SSE development program should be modified to incorporate both IV&V of the SSE and functional checks of the safety and reliability of the software developed using the SSE.

NASA Response: The Software Support Environment (SSE) includes not only the set of tools that will be used for development of all operational software to be used aboard the space station, but also the tools and standards that can be used to check the software for quality and safety. The issue of software safety and reliability is currently being addressed in a change request to SSP 30309, "Safety and Risk Assessment Requirements for the Space Station Freedom Program." The requirements of SSP 30309 will be incorporated into the SSE standards to ensure that software controlling safety-critical functions has an acceptable level of risk since failures, errors, and adverse environmental conditions will occur. The Lockheed Missiles and Space Corporation (LMSC), the prime contractor for development of the SSE, currently employs an independent validation and verification (IV&V) contractor, Science Applications International Corporation (SAIC). This contractor, although employed by LMSC, functions totally independent of the development team and serves as an effective SR&QA check on the system development effort. They will in fact independently validate and verify the software in the SSE.

d. **Finding**: *There have been many good "preliminary" or "quick look" studies performed to support SSFP preliminary design activities. These studies often involve broad assumptions which are used to fix certain items while others are varied. This is an excellent approach. History tells us it is important to document the extent and nature of these assumptions very clearly. This will minimize the possibility that people reading these studies in the future will mistake areas not examined for those examined and excluded as potential problems.*

Recommendation: The SSFP management should develop and disseminate a standard policy for documentation of assumptions in preliminary studies. This policy should clearly differentiate among things assumed and not studied, items given a partial examination, and those studied fully.

NASA Response: NASA concurs with the recommendation that better tracking procedures of quick-look and preliminary studies should be implemented. Much insight has been gained through "lessons learned" and documentation of findings and recommendations. If similar documentation and/or a data base were to be developed for SSFP quick-look studies, a considerable amount of redundancy and duplication of effort could be eliminated. In the best interests of continuity and productivity, any study whether large or small needs to be documented as a matter of standard operating procedure. NASA will investigate and review what policies and/or management instructions provide requirements for documenting assumptions, conclusions, and any preliminary or quick-look studies. If current policies and instructions do not provide for this requirement, NASA will develop and publish appropriate policies or management instructions that document assumptions in preliminary studies.

e. **Finding**: *It is understood that consideration is being given to expanding experiments or the storage of experimental gear into the nodes. This would make them essentially undifferentiated from the attached modules with respect to safety considerations.*

Recommendation: SSFP management should establish a policy on node use as soon as possible. However, since there will always be the possibility that the nodes will be used for experimental or storage purposes, they should receive the same safety scrutiny as the remainder of the Station.

NASA Response: Consideration is being given to expanding the experiment capability into the nodes. This change is subject to the same ongoing, rigorous safety scrutiny, as is the entire SSFP design including Failure Modes and Effects Analyses (FMEAs), hazard analyses, and human engineering analyses.

All uses of the nodes will be restricted by the requirement for crew emergency egress through the node from any module.

f. **Finding**: *The baseline design does not include a provision for cleanup of hazardous spills in the open cabin area. Prevention of the spills appears to be the sole countermeasure approach.*

Recommendation: The Space Station should include the capability and equipment for the crew to manage and resolve a toxic spill in the open areas and prevent spills from propagating to the remainder of the Space Station.

NASA Response: NASA accepts the recommendation of the Panel concerning the addition of the capability and equipment to enable the crew to cleanup hazardous spills. While there is currently no requirement for "hazardous spill kits," the Space Station Freedom (SSF) Safety and Product Assurance Office, Code SSQ, is preparing a change request to SSP 30000 to require the provision of spill kits for the management of hazardous spills.

g. **Finding**: *There is concern that the use of the current Shuttle space suits will be inadequate to meet the time line required for the erection of the Space Station Freedom.*

Recommendation: NASA should go all-out to develop the new higher pressure suit so that it can be made available for timely use in the construction of the Space Station.

NASA Response: NASA is developing a space station optimized suit that is not planned to be operational until Permanent Manned Capability (PMC) is achieved. During space station assembly and during the man-tended phase of operations, the crew will function from the Space Shuttle. The crew will use the current Space Shuttle suit that has demonstrated excellent glove mobility, much better than is currently afforded by the newer high pressure glove designs. Also, the prebreathing issue raised in previous ASAP findings is eliminated as a requirement because Orbiter Extravehicular Activity (EVA) operations lower cabin pressure to 10.2 psi when the Shuttle 4.3 psi suit is used.

NASA believes that the proven Space Shuttle suit, with improvements and additional life certification tested as required, will be adequate to meet the time line for the erection of Space Station Freedom; and will be a safer, more conservative alternative than a newly developed high pressure suit.

C. AERONAUTICS

Finding: *Review of the safety policies associated with the NASA flight research programs at Langley, Ames, and Dryden indicate good appreciation of the importance of a comprehensive aviation safety program that is closely linked to, but independent of, the flight projects. Whereas there are similar functions and activities being followed by all flight research centers, they operate under different operational procedures and are organized differently. The safety procedures of each center seem to have evolved separately. As an example, the Basic Operations Manual published by Dryden establishes the Chief Engineer as the focal point for aviation safety with the Aviation Safety Officer assigned to the Flight Crew Branch, whereas the Langley Flight Research Program Management document establishes the Chief, Low-speed Aerodynamics Division as responsible for the overall flight research program including aviation safety with the safety officer in a subordinate branch.*

Recommendation: Headquarters should review the flight research policies and procedures of the concerned flight research centers to determine if their existing flight safety procedures are adequate or if it is appropriate to standardize on a NASA-wide set of procedures for conducting flight research.

NASA Response: The flight research policies and procedures of the Flight Research Centers have been reviewed by NASA Headquarters with inputs from the Offices of the Associate Administrator for SRM&QA (Code Q), Aeronautics and Space Technology (Code R), and Space Flight (Code M). Given the diverse nature of aircraft operations within NASA (including research and development, program support, and administrative flights), absolute standardization of airworthiness/operations is neither appropriate nor required. These findings were further validated when presented to the Intercenter Aircraft Operations Panel that includes members from each installation that operates aircraft, representatives from the Headquarters Aircraft Management Office, the NASA Aviation Safety Officer, and advisors from Headquarters Program Office. The Panel has agreed that the Senior Aviation Manager at the Center will be responsible for implementing safety policies associated with NASA Flight Research Programs. These procedures will be delineated in a new Headquarters NMI that is being drafted.

D. RISK MANAGEMENT

a. **Finding**: *In 1988 NASA issued several NMIs and NHBs that provide policies and direction designed to improve the identification, evaluation and disposition of safety risks. In particular, NMI 8070.4 titled "Risk Management Policy for Manned Flight Programs" calls for a risk management process that includes categorization and prioritization of "risks" using qualitative techniques for ratings of the frequency expectation and severity* *of the potential mishaps. The documents also provide for use of quantitative risk analysis to provide a more definitive ordering of risks for purposes of risk management.*

<u>Recommendation</u>: The risk management policies and initial implementing methodologies which have been issued in 1988 need to be evolved further. Practical quantitative risk assessment and other relative risk-level rating techniques should be actually developed. They should then be applied to help define the risk levels of flight and ground systems.

<u>NASA Response</u>: The risk management function is evolving. NASA is vigorously refining the NASA Management Instructions (NMIs) and NASA Handbooks (NHBs) to reflect the latest risk management policy developments. Independent risk assessments are being performed on Galileo and Ulysses payloads utilizing updated risk management methodology. This risk methodology includes the development of credible accident scenarios derived from initiating events that could cause potential mishaps. It incorporates both qualitative and quantitative system response analyses of initiating events induced by hardware or software anomalies malfunction(s), human error, environmental influences, or probable combinations of these factors. Also, the risk assessment methods are being restructured as further development and state-of-the-art knowledge are gained from ongoing risk assessment activities arena. Practical quantitative risk methods and risk-level techniques are being matured by NASA in structured workshop sessions and supporting policies with a view toward incorporation into the risk management efforts in the National Space Transportation System (NSTS), space station, and payload areas.

b. <u>Finding</u>: *The Panel has found strong commitment by each of the Center Director Offices to the rebuilding of the System Safety Functions in NASA. They have provided valuable guidance, encouragement and some level of financial support to the difficult restructuring, staffing and new policy implementation activities at their respective Centers. We are concerned that program resource cuts may be beginning to erode the progress which has been made.*

<u>Recommendation</u>: In addition to continuing their good work we believe that additional vigorous assistance is required on the part of each Center Director's Office to assure the allocation of resources that are necessary so that the promising progress toward a truly effective Systems Safety capability does not falter and wither away after a few successful STS flights. The Center Directors must be seen as major champions of safety engineering within NASA.

<u>NASA Response</u>: NASA strongly agrees that a key element to the successful implementation of a NASA-wide Safety Program is the committed support of the Center Directors who must continue to be the champions of safety engineering. To ensure that progress made at the Centers is maintained, the Office of the Associate Administrator for SRM&QA, Code Q, has initiated the following efforts:

(1) A Center Director/Program Manager Safety Awareness Training Program is being developed. This program will address the benefits and cost-

effectiveness of a strong safety program. Also, it will provide information concerning the role and responsibilities of the NASA Headquarters Safety Division, Code QS, in relation to the Centers and Acquisition Program.

(2) The Associate Administrator for SRM&QA conducts quarterly meetings with the Centers SRM&QA Directors to discuss progress and problems relative to their individual programs. Problems of similar scope experienced by more than one Center are addressed together to form a stronger justification base when additional resources are required. Information on advances or successful new initiatives are also exchanged among the Centers SRM&QA Directors.

(3) The equal relationship of the Associate Administrator for SRM&QA with other NASA Associate Administrators provides the level of authority and visibility to proactively resolve any anticipated problems of budget, manning, or lack of safety focus at a Center or on an acquisition program.

(4) Site surveys of Center and program activities by Code QS periodically review the effectiveness of their safety programs. Results of these surveys, positive and negative, are briefed to the cognizant Center Director or Program Manager, as well as the Director of the NASA Headquarters Safety Division. Problems, whether real or perceived, are presented to the Associate Administrator for SRM&QA for appropriate corrective action.

c. **Finding**: *At JSC there is a clear commitment from the Director's level down to implementing the general policies and requirements of NMI 8070.4, and to improving techniques for risk assessment and risk mitigation. We observed that the SRM&QA organization is still not completely staffed. The organization has assembled hazard information that is used in the decisions of whether or not to fly. Whether this same information can be used to identify safety-enhancing changes has yet to be examined.*

Recommendation: Examine the collected data to see if it can be used to identify safety-enhancing changes, and, if so, define these changes. (P. 9)

NASA Response: The review process for National Safety Transportation System (NSTS) safety issues and associated hazard reports, conducted by the System Safety Review Panel (SSRP) and the Levels I and II Program Requirements Control Board (PRCB), results in thorough review of the safety problems involved. As part of this process, recommended changes required for hazard mitigation and/or control are actions levied on the responsible NSTS element(s). Detailed responses and presentations are made to the review boards up to the Level I PRCB, which is chaired by the NSTS Program Director. Therefore, identifying and recommending safety-enhancing changes in response to identified hazards are integral parts of the hazard review process at levels up to and including NASA Headquarters. These changes include: revisions/changes/additions (to Flight Rules and Launch Commit Criteria); improvements in manufacturing, inspection, test, and quality control procedures; and design changes to mitigate or reduce the risk involved (subject to budgetary review and approval by the NSTS Program Director).

d. **Finding**: *At JSC the ASAP was presented a new approach to hazard rebaselining and rating, and a new format for the Mission Safety Assessment report (MSA). The new report is basically a set of evaluated fault trees which identify the potential system mishaps which might result from various hardware or human faults. For STS-26, 25 "significant risk" mishaps were "selected" for evaluation. All items selected had worst-case severity levels of "loss of crew and/or vehicle." All items were also rated as "unlikely," which was the lowest probability rating used in the hazard rating matrix. Thus, the MSA did not address even the relative risk-levels of the selected potential mishaps. However, the system safety organization did not color-code various faults - red, which designates that Improvement is Highly Desirable (IHD). Because all of the items elected for inclusion in the MSA are rated as unlikely to occur and therefore "safe to fly," there remain a large number of undifferentiated items designated IHD.*

Recommendation: The ambiguity regarding risk levels implied by the red color-coded MSA needs to be removed. NASA needs to provide a much more objective (quantitative) and data based risk assessment methodology that will differentiate the "unlikely" events for purposes of assessing the principal contributors to risk on STS and Space Station type programs.

NASA Response: The Mission Safety Assessment (MSA) focuses in more detail on risks considered issues for the current and subsequent launches. Since the ASAP visit, the MSA has been reevaluated and is now considered a program baseline safety assessment to be updated periodically, not mission specific. It is derived from the approved Hazard Report (HR) set, which forms the program baseline safety risk. Renaming of the document is under consideration and the safety community is developing a replacement document that will be mission-specific and unique, the final title of which is not yet determined. It will provide visibility to top management of significant changes or potential significant changes to the baseline safety risk. It will indicate launch constraints and resolved safety risk factors.

Basic requirements for the mission-unique safety risk assessment report need to be changed, and changes to the requirements are being pursued. The requirement for the MSA to be published 30 days prior to a launch is unrealistic as some safety risk data probably will not be achieved in time for consideration in the report as happened on STS-26. It is expected that the new requirement for safety risk assessments will be keyed to milestones such as the Flight Readiness Review (FRR) and the L-2 Day Review, and it will have a format that will permit rapid, last-minute updates.

All risks in the STS-26 were considered "unlikely," but were also more significant than others that had been received at the time of publication. Several HRs were subsequently submitted with a probability of occurrence of "likely," and they have been incorporated in subsequent MSA editions. All the events had the potential of being catastrophic events.

The fault-tree approach presents these basic and conditional events. From this analysis, the MSA evaluated the hazard controls in the design and procedural area (i.e., redundancy, safety factors, launch commit criteria) for possible improvement to further mitigate the risk. The MSA used a qualitative approach to assessing the relative levels of risk. The NSTS safety community is considering changes to the three-level probability of occurrence to provide greater differentiation. Also, future editions of the MSA will use the results of probabilistic risk assessments, when available, to help define the relative level of risk for prioritization.

NASA's effort to identify and quantify risk contributors has proceeded with several different approaches: probabilistic risk assessment (PRAs), individual statistical analyses, and prioritization of Failure Modes and Effects Analysis/Critical Items List (FMEA/CIL) items (system/component coupled with a Criticality 1 failure mode). Relative to the PRA effort, a risk assessment for the Galileo mission [which uses a radioisotope thermoelectric generator (RTG) power source] was conducted. The assessment focused on events leading to breech of the RTG case. Shuttle element risks and individual risk contributors were developed using fault trees, random failure distribution approximations, and Bayesian techniques.

However, none of the above efforts obviate the need for detailed, accurate, and easily accessible data bases containing test and flight failure data. The current Program Compliance Assessment Status System (PCASS) data base contains problem reports on component failures. For analysis purposes, data fields containing the specific FMEA failure mode need to be included to facilitate initial analyses; such an effort is now under consideration. A space station requirement document for a failure history data base is being developed. Apart from individual assessments and development of data bases, a more quantitative approach for identifying and assessing principal risk contributors has been explored using the current hazard analyses as a foundation. In this approach, detailed causes and scenario paths leading to damage states are developed. Likelihoods ascribed to the scenario nodes and, in turn, probabilities are approximated for each potential path and damage state. Examples using auxiliary power unit hazards have been developed. This approach is being evaluated as a quantitative enhancement for hazard assessment.

e. <u>Finding</u>: *Functional areas such as system-safety engineering at the Centers appear not to have received the resource support necessary to fulfill their responsibilities. The SRM&QA organizations at the centers appear to be relatively loosely coupled to headquarters.*

<u>Recommendation</u>: The various systems safety organizations throughout NASA should get stronger assistance from Headquarters especially regarding financial support.

<u>NASA Response</u>: NASA agrees that Center SRM&QA organizations should continue to receive strong support from Headquarters. During fiscal year (FY) 1989, 50 percent of the Headquarters SRM&QA budget is being transferred directly to the Centers. In FY 1990, we plan to increase this to 70 percent. Since January 1986, we have been able to increase the number of civil service and Jet Propulsion Laboratory personnel directly assigned to SRM&QA functions by approximately 39 percent. During that same period, the number of support contractor personnel performing SRM&QA functions has increased by nearly 95 percent. These statistics verify that the Centers have a strong and eloquent

voice in Headquarters. As a consequence, NASA feels that within the context of existing Federal Budget constraints, the Center SRM&QA organizations have been well supported.

Center SRM&QA organizations report and are directly responsible to the Center Directors. The Office of SRM&QA functions in a senior staff capacity at Headquarters providing a focal point for NASA-wide SRM&QA activities, programmatic direction, policy formulation, and resources support. The link

between Headquarters and field SRM&QA operations is sufficiently strong to provide proactive and vigorous SRM&QA program management.

f. **Finding**: *At MSFC the ASAP found an excellent SRM&QA organizational structure and good progress in staffing it with experienced engineering personnel. As other centers have done, they engaged the services of two contractors to aid in developing the analysis techniques for practical, more quantitative risk assessment and statistical evaluation of data bases.*

Recommendation: MSFC is to be commended for their progress in evolving its SR&QA function and these efforts should receive continuing high-level support.

NASA Response: The achievements of the Safety, Reliability, Maintainability, and Quality Assurance (SRM&QA) organization at Marshall Space Flight Center (MSFC) are recognized and applauded. Also noteworthy is MSFC taking the lead in establishing the management and engineering requirements for Maintainability, which is a relatively new key discipline within the Agency. MSFC and the other Center SRM&QA organizations will continue to receive the high-level support required to ensure their continued viability as effective spokespersons for System Safety, Reliability, Maintainability, and Quality Assurance.

APPENDIX B. OPEN ITEMS FROM 1988 ANNUAL REPORT

A. SAFE RETURN TO FLIGHT

1.d. Space Transportation System (STS) Management

OPEN ITEM: Reevaluation and recertification workload and prevention of human error at KSC.

STATUS: The required reevaluation and recertification of Space Transportation System (STS) hardware and software systems involved in returning the Space Shuttle to flight presented NASA and the Shuttle Processing Contractor (SPC) with a monumental challenge and opportunity. NASA and its contractors are meeting the challenge of returning the STS to operational status by scrupulously following the recommendations and instructions set forth by the Rogers Commissions and other forums.

The Kennedy Space Center (KSC) also has been meticulous in carrying out its duties in accordance with the SRM&QA guidelines and requirements from NASA Headquarters. The NASA and contractor management and work force at KSC believe in the "Safety First, Schedule Second" philosophy. They have developed the mind-set, and the disciplined work and documentation procedures to help avoid human error and danger areas, such as relaxing attention to detail, shortcutting test procedures, or ignoring persistent problems.

A comprehensive testing, training, and certification program has been implemented to acquire and maintain a qualified work force for the STS group operations. Additional personnel have been tested, hired, and trained for the highly technical tasks involved in testing and processing the STS elements for flight, and to augment the safety and quality disciplines. Automated documentation and work authorization systems have been established to lessen the paperwork burden and to assure more efficiency in the work control process. These systems also provide faster and more accurate disposition of problems, appropriate management visibility, and reduced probability of human error.

The Office of the Associate Administrator for SRM&QA at NASA Headquarters, that was established as part of the restructuring process and at the recommendation of the Rogers Commission, has enacted a broad and thorough monitoring/audit process covering all aspects of the SRM&QA discipline in all NASA programs. This process involves developing, disseminating, monitoring, and enforcing policies, quidelines, and procedures for recognition and implementation of SRM&QA concepts and requirements. The SRM&QA requirements and guidelines assure that the SRM&QA philosophy and policies are deliberately factored into all aspects of a NASA program (from concept/design/development to testing/certification/acceptance).

In support of the STS return-to-flight, the Headquarters-level SRM&QA organization has prepared and distributed policy and guideline documents, and long-range plans; provided real-time support to hardware/software development programs; and performed routine and special staff assistance surveys.

Accordingly, KSC has supported this overall SRM&QA effort in the context of its assigned responsibilities by establishing appropriate organizations and staffing; implementing the Headquarters-level policies and requirements; and developing and implementing appropriate local SRM&QA procedures, regulations, and guidelines.

At KSC, the STS recovery and return-to-flight effort have involved a vast number of specific, tangible tasks including the reexamination and overhaul of policies and procedures; redesign, testing, and recertification of hardware and software; assessment and adjustment of management philosophy and organizational structure; safety priorities; documentation systems; and decision-making processes. The tasks also include investigation of personnel factors such as shift work, overtime, and fatigue; as well as less tangible, but equally important, factors such as personnel testing and training, incentives, dedication, morale, and attention to quality.

Each factor in the rebuilding process contributed to the reevaluation and recertification of hardware and software – whether it concerned actual redesign and testing of hardware and software or involved training and qualification of personnel, better documentation systems, strict overtime regulations, or morale of the work force.

Two highly successful STS missions in 1988, one in 1989, and the ongoing successful processing of the next mission attest to the effectiveness of the combined efforts undertaken at KSC to return to flight.

2. Reassessment of Risk

OPEN ITEM: Methodology and implementation for conduct of FMEA/CIL/Hazards Analyses. Prioritizing of items.

STATUS: Based on the National Space Transportation System (NSTS) document NSTS 22206, "Instructions for Preparation of Failure Modes and Effects Analysis (FMEA) and Critical Item List (CIL)," the Office of the Associate Administrator for SRM&QA, Code Q, has developed a NASA Handbook for Agency-wide use. The handbook is NHB 5300.A(1G), "Failure Modes and Effects Analysis (FMEA) and Critical Items List (CIL) Requirements for NASA Space Programs." It is complete and awaiting concurrence of the NASA Headquarters codes. The document NSTS 22254, "Methodology for Conduct of NSTS Hazard Analysis (HA)," is being revised, and a draft is scheduled by mid-1989. The revised NSTS 22254 will provide a consistent approach to hazard analysis. The revision will comply with the following documents being developed by SRM&QA: NMI 8070.4, "Risk Management for Manned Flight Programs;" NHB XXXX, "NASA Risk Management Program: Rules and Responsibilities;" NHB XXX, "NASA Risk Management Program: Tools and Techniques;" NHB 1700.1(V1-B), "Basic Safety Manual (Draft);" and SSP 30309, "Safety Analysis and Risk Assessment Requirements."

The NSTS Program developed and issued document NSTS 2249, "Instructions for Preparation of Critical Item Risk Assessment." This document provides a method of prioritization and categorization of failure modes by severity of effects and likelihood of occurrence. Code Q is developing two documents to be used Agency-wide that address prioritization techniques of CILs for risk assessment: "NASA Risk Management Program: Roles and Responsibilities" and "NASA Risk Management: Tools and Techniques." Additionally, utilizing NSTS 22491 and contractor reports, Code Q developed ranked lists of the "Top 25" most critical CIL items for each Space Shuttle element. Code Q is conducting trend assessments that include examination of problem frequency, current status, resolutions/current control, and recommended action for each CIL item for each Shuttle element.

The NSTS Program developed a computerized accounting system known as the System Integrity Assurance Program (SIAP). A feature of SIAP is the Program Compliance Assurance and Status System (PCASS), which is a computer-based information data base system that integrates a number of information data base systems including: the Integrated Problem Assessment System (IPAS), Hazard Data System, FMEA/CIL System, Closed-Loop Accounting System (CLAS), Requirements Accounting System (RAS), and Programmatic Issues System. PCASS is used primarily to facilitate a closed-loop management system that allows program, element project, and SRM&QA managers (and other users) to determine the status of requirements, problems, trends, risk decision, and critical item action. PCASS and contractor sources are used to baseline risk assessment indicators including Launch Vehicle Reliability, Mission Safety Assessments, Overall Hazard Review, Flight Software Trends, Payload Problem Trends, and Limited-Life Item Trends. These indicators are updated for review prior to each Orbiter flight.

B. SAFETY, RELIABILITY, MAINTAINABILITY AND QUALITY ASSURANCE PROGRAMS

1.b. General

OPEN ITEM: The dangers of complacency.

STATUS: The Office of the Associate Administrator for SRM&QA is continuing to expand the audit process through independent safety assessments to ensure that problems and undesirable trends are identified and communicated to cognizant management levels for proper disposition. A key function in this process is to monitor and provide assessments of all problems that could adversely affect personnel morale and safety awareness or foster an attitude of complacency.

The NASA Headquarters Program Assurance Division, Code QP, is playing a vital role in assuring the National Space Transportation System (NSTS) and associated missions safety and mission success. An example of Code QP involvement is the review of past and ongoing committees' findings on NASA programs to evaluate all launch and flight safety concerns. The dangers of complacency have not been exempt from these evaluations that incorporate a system and decision-making process to include checks and balances to manage system alterations and reporting procedures.

The NASA Headquarters Safety Division, Code QS, Safety Awards Program is being developed to provide top-level recognition of individuals or facility groups who have demonstrated superior safety performance. In addition, the

NASA Quality and Productivity Improvement Programs Office, Code QB, has implemented a program for promoting and evaluating quality and productivity within NASA and its contractor community. This program is dedicated to promoting quality and productivity concepts, techniques, and methodology throughout the Agency.

In cooperation with the NASA Safety Program, the Space Station Freedom Program, and all other Shuttle-related activities, the Manned Flight Awareness (MFA) Program under the cognizance of the Office of Space Flight and the MFA Panel Chairman have been upscaled, realigned, and strengthened in its commitment to mission success and astronaut safety. The primary goal of the MFA Program, considering the impact of STS-51L, has been to revitalize and enhance morale, motivation, and dedication among all NASA and NASA contractor employees associated with the Space Shuttle Program including associated payload activities. All MFA Honoree Program events since STS-51L have included the direct "in-person" staunch support of NASA and NASA contractor top management. Each of these events has included participation by the NASA Administrator and his staff, the Associate Administrator of the Office of Space Flight and other Associate Administrators, Chief Executive Officers of the major aerospace companies supporting NSTS, and members of the astronaut corps. Of note is the fact that these MFA Honoree events have taken place on nonlaunch as well as launch occasions.

Also, the MFA Program is initiating the awards of Flight Safety Awareness Certificates (to be presented by the astronauts) to individuals who identify a safety problem that could precipitate a mishap. Further, the MFA Program has been expanded in scope to include subcontractors, vendors, and payload participants. Astronaut visits and discussions on flight safety awareness and "Safety First, Schedule Second" are being conducted at all NASA and NASA contractor organizations, activities, and facilities both within and outside the NSTS Program. The chain of safety awareness has and will continue to swing full circle in every facet of the NSTS Program.

The audit process, Code QP involvement, the Safety Awards Program, the Code QB Quality and Productivity Improvement Program, NASA Center direct involvement, and the upscaled MFA Program are all dedicated to the elimination of complacency and the preservation of safety awareness in all NASA programs and projects including NSTS.

1.d. General

OPEN ITEM: Study of potential design-induced human errors.

STATUS: NASA Headquarters Safety Division has taken specific steps to reduce human-induced errors. Code QS has developed a draft NASA Management Instruction for Human Engineering that defines the policies and responsibilities for the conduct of a structured Human Engineering Program at all levels of NASA. A draft NASA Handbook has been developed for human engineering in manned space flight systems, software, and facilities that structures the human engineering process. A draft Human Engineering Program Plan for the Space Station Freedom Program has been developed to assist in identifying the various ongoing human engineering efforts and integrating these efforts with the overall Safety Program. The preparation of a Human Engineering/Safety course to be given to Safety Engineers has been funded in an effort to provide awareness of the human engineering issues affecting the Safety Program.

Investigation has begun into the available Human Reliability Assessment Methodologies and Tools for applicability to NASA Programs.

C. SPACE SHUTTLE ELEMENT STATUS

3.a. Orbiter

OPEN ITEM: Orbiter OV-102 strain gauge calibration.

STATUS: The allowable flight envelope was revised at the Design Certification Review in March 1988. Certification was derived from 6.0 loads/stress analysis. The scope of the analysis used in certification included 60,000 structural components and 30 major structural elements including the wing, vertical tail, and mid-fuselage. Further analysis results indicate that the majority of the Orbiter structure has positive margins, and constraints have been defined for critical structures (wings, tails, aft fuselage, OMS pods, and wings leading edge) to ensure positive safety margins. Since launch probability can degrade due to constrained structure, structural modifications are being made as program requirements dictate. In consonance with previous ASAP recommendations, a plan is in place to add strain gauges to the Space Shuttle Columbia (OV-102) wing, tail, payload bay door, mid-fuselage, and elevons for its next flight (STS-28); and to recalibrate and reconnect a number of pressure measurements. This plan includes a wing calibration during OV-102 major modification.

Mid-body thermal measurements are being installed on Space Shuttle Atlantis (OV-104) (Flight 3) to collect and substantiate the 6.0 thermal data. These will be operational on the next flight. Tile temperature measurements are being added for the next OV-102 flight. The quantity of measurements will be determined by the Kennedy Space Center (KSC) workflow and the Shuttle budget in FY 1989. The plan that NASA referenced in 1988 for Orbiter OV-102 strain gauge calibration is being implemented at KSC. Over 200 strain gauges have been installed on OV-102 (Flight 8) currently scheduled for launch on July 1, 1989.

3.d. Orbiter

OPEN ITEM: APU turbine wheel blade cracking concerns.

STATUS: The causes of the turbine wheel blade cracking are not yet fully understood; however, there is a strong correlation between the incidence of blade cracks and the number of hot starts. The blade cracks exhibit the characteristics of high cycle fatigue, possibly due to a combination of the high thermal gradient-induced stresses during hot starts and the excitation of the turbine blade edge resonant frequencies by the hot gas dynamics. Additional testing and analysis using instrumented turbine wheels are continuing to determine the causes and the solutions to the cracking phenomenon.

On the basis of the turbine wheel cracks mapping conducted last year and the correlation with hot starts, the original Auxiliary Power Unit (APU) turbine wheels are limited to 16 hot starts before removal and inspection. Newly manufactured turbine wheels that reflect the latest process changes and controls are restricted to 24 hot starts prior to removal and inspection.

The long-term solution for the turbine blade cracking problems includes a new turbine wheel designed for 75 hours of crack-free life. This corresponds to 50 mission duty cycles and 120 hot starts. The 75-hour turbine wheel design will be phased into the current APUs during the latter half of 1989.

The new 75-hour turbine wheel features a full blade width tip shroud, a lower blade density, and an optimized blade design for the current APU operating conditions. The thicker turbine blade edges combine with the full width tip shroud to raise the blade edge resonant frequencies by a factor of 1.6. The new turbine wheel has a reduction in gas-induced dynamic stress and fuel consumption.

An Improved APU (IAPU) design will be phased into production during the first half of 1990. The IAPU will provide a variety of improvements including the new 75-hour turbine wheel.

5.a. Launch, Landing and Mission Operations

OPEN ITEM: KSC STS launch processing working environment.

STATUS: For factors such as overtime, worker fatigue, worker incentive, safety, and schedule pressure, the work environment continues to be a recognized concern on the part of NASA and NASA contractors. The highly technical and intense work environment associated with all aspects of Space Transportation System (STS) operations is one in which human error is a constant concern because of its propensity to induce human error that might result in danger to the safety of personnel and to flight and/or ground equipment.

Policies, procedures, and guidelines regarding operations methodology, scheduling, and personnel assignment have been and will continue to be devised and put into place. Management authority at all levels is sensitive to any symptoms or indications of potential problems that could, in any way, jeopardize the safety or health of personnel, or the safety and integrity of flight and/or ground hardware. The policy of "Safety First, Schedule Second" is recognized, accepted, and practiced by both NASA and contractor management and workers; it has become second nature in all actions, plans, and decisions regarding STS operations.

Strict policies, for example defining maximum work time for personnel in critical jobs, have been enacted (KMI 1700.2) to assure that conditions of worker fatigue, overwork, or burnout do not become factors that may be detrimental to safety of personnel or equipment, or to quality of work.

Established limitations relative to maximum work schedules for personnel are strictly enforced. A waiver procedure is in place if any critical personnel should be required to work more than certain established maximums, such as: 12 hours per day, 60 hours per week, 7 consecutive days per week, 240 hours for 28 days, and 2,500 hours for 1 calendar year. Policies are already in effect for control and approval of overtime and holiday work for civil service employees (KMI 9610.1C).

5.b. Launch, Landing, and Mission Operations

OPEN ITEM: Human resource problems at KSC to match work load including worker morale and productivity.

STATUS: The human resource factor continues to be a management concern that has been alleviated to some degree by additional hiring, performance incentives, mandatory training, and a concerted attempt by all levels of management to improve morale.

Following STS-51L, a survey was performed to determine present training status and to define long-term training requirements. On the basis of this survey, a comprehensive training program was established and implemented by NASA and on-site contractors, featuring several key methodologies designed to increase the efficiency of the training process. Some of the program features include: pre-employment testing of Space Transportation System (STS) technician applicants, certification training and testing in over 400 STS-related technical subjects, retest after 1 year of certification, computerized record keeping, three-shift training, and a tightly controlled attendance record system. "Learning centers" that locate classroom training in the vicinity of the actual work area were instituted. High volume, high priority work tasks, such as Thermal Protection System (TPS) repair, are accommodated by incorporating special schedules and increasing the size and numbers of courses offered. The launch team undergoes special training and is stand-boarded to assure qualification. Off-site training is provided to assure that visiting technicians meet the local environmental requirements, technical qualifications, and certification requirements. Special training on appropriate technical subjects is provided to personnel performing STS operations activities for off-site locations, such as White Sands and Dryden Flight Research Center.

Overall worker efficiency has been enhanced by the training program, as evidenced by comparison of the number of new jobs with the number of work-related incidents. Worker incentive has been increased by the anticipation of higher job qualifications resulting from the training, as well as by the official certification that is awarded subsequent to training and successful certification testing.

Federal Aviation Administration technical certification testing techniques, methodology, and criteria have been modified/adapted to the unique requirements of the Kennedy Space Center STS technical operations environment. It is reported that the pretested new-hires have a record of learning faster on the job and of accepting more responsibility faster than noted previously.

Overall, worker and management incentive, morale, sense of achievement, and pride in the program have been greatly enhanced by the two highly successful Space Shuttle missions in 1988, and also are evident in the ongoing hardware processing for the next mission scheduled for early 1989. Enthusiasm, pride, and sense of achievement are exhibited by both NASA and contractor management and workers in their demeanor, morale, and dedication. It carries over and is evidenced by a recognizable increase in eagerness, willingness, and quality of work. It has had a tangible, positive effect on the "character" of the work environment.

The contractor and civil service manpower resources are being increased in both number and quality in accordance with policy, requirements, and budget capability.

5.c. Launch, Landing, and Mission Operations

OPEN ITEM: Launch frequency (manifest) concerns.

STATUS: The process of changing Space Shuttle software is a rigorous, disciplined, well-documented process. Software changes are defined on software change requests (CRs) by members of the NASA requirements community. These are documented as changes to requirements documents under the rigorous configuration control of the Shuttle Avionics Software Control Board (SASCB), which is chaired by the Manager of the NSTS Engineering Integration Office. No part of any software requirements document can be altered without the approval of this board, and then only after a thorough review and concurrence by the requirements community. The review and approval process is thoroughly and completely documented through detailed minutes of Board proceedings and incorporation of approved requirements into the detailed design and maintenance specifications, user's guides, and Program Notes and Waivers Document. Additionally, since STS-51L, the engineering design community has documented the design rationale associated with each mission-unique design data parameter. Documentation includes the history, limits, constraints, and trends for each parameter as well as the interrelationships of the parameters to each other and to other significant flight characteristics. NASA believes that this constitutes a thorough and complete documentation of the design and implementation rationale for Shuttle flight software.

The knowledge base required to develop effective Shuttle crew procedures is extensive and multi-disciplined. Development of these procedures involves operations and engineering personnel as well as astronauts since detailed knowledge of the Shuttle, operating environments, and crew capabilities is required. Approval and validation of crew procedures involve formal reviews and simulator checkouts. Baselined Shuttle crew procedures are exercised extensively during simulations. We believe that the majority of the human factor considerations are found during procedures validation and during the extensive exercises and procedures usage in the simulators. Moreover, crew procedures development specialists with assistance from spacecraft designers are pursuing methods to improve the human factors aspects of procedures development. The methodology and expertise developed through this effort are being injected in real-time into the procedures developed for the Shuttle.

Following STS-51L, mechanisms were put in place to ensure that there is adequate training time. A minimum of 11 weeks of Shuttle mission simulator training time is now the standard for NSTS flights. As part of the flight preparation process, each flight is reviewed to determine if additional training time is required. Any reduction in training time from the standard must be approved by the Level II Program Requirements Control Board.

5.e. Launch, Landing, and Mission Operations

OPEN ITEM: Procedures for approving late software changes at JSC/KSC.

STATUS: Late changes to Orbiter Avionics, Space Shuttle Main Engine (SSME) Controller, and Ground Launch Sequencer software can be made. Late changes to the Orbiter Avionics software can be physically implemented via tape or satellite links. Changes to Orbiter Avionics software include modifications to the software program code and program constants or I-Loads; these changes must be formally approved by the Shuttle Avionics Software Control Board (SASCB). Approval by the SASCB often will require a complete test evaluation of the change. As with the Orbiter Avionics software, changes to SSME Controller software include modifications to the software program code and constants; these changes also are generally approved by the SASCB. Occasionally, late changes for SSME Controller software will be submitted to the Problem Review Control Board (PRCB) for approval. Changes made to SSME Controller software cannot be transferred electronically to Johnson Space Center (JSC) or Kennedy Space Center (KSC). Therefore, changes are incorporated on tapes and sent to the appropriate site. Changes to the Ground Launch Sequencer software can be made within 2 hours of launch time. Changes are documented as waivers or deviations from Launch Commit Criteria or File II Operations and Maintenance Requirements of Specifications (OMRS).

D. SPACE STATION PROGRAM

1. Space Station Computing Systems

OPEN ITEM: Space Station Computing Systems

STATUS: As stated in the 1988 report, the design and production of components are divided into four work packages delegated to Marshall Space Flight Center (MSFC), Johnson Space Center (JSC), Goddard Space Flight Center (GSFC), and Lewis Research Center (LeRC). Therefore, the integration of software development is recognized as a demanding task. Lockheed Missiles and Space Corporation (LMSC) continues to develop a common Software Support Environment (SSE) for the entire Space Station Freedom Program (SSFP). The SSE will allow each development contractor to design, develop, and test their software to assure compatibility and integration when operational. The Multi-Systems Integration Facility (MSIF) will be the verification and validation activity where integration and testing will take place under the leadership of Level II and its support contractor. The concept of how to attack the software integration task appears workable and is one in which NASA can have confidence of achieving successful SSFP software/computing systems.

A concern has been expressed relative to the Data Management System (DMS) for the space station: the quantity and scope of data that the DMS will have to handle that has been addressed in Section 8, SSP 30000, the Program Definition and Requirements Document (PDRD); with rationale provided in more detail in SSP 30261, "Data Management System," and JSC 30226, "Technical and Management Information System Functional Requirements Document." More documentation is planned and will be available for the Preliminary Design Review scheduled for Spring 1990.

The recommendation that provision be made for planned upgrades for both hardware and software of the space station computing systems is implemented by provisions of the space station Program Requirements Document (PRD) and the PDRD.

2. Crew Emergency Rescue Vehicle (CERV)

OPEN ITEM: Crew Emergency Rescue Vehicle Activities

STATUS: The Space Station Freedom Program (SSFP) Safety and Product Assurance Office, Code SSQ, agrees that a crew rescue capability is a mandatory requirement on the space station. There is ample medical evidence to support the need for prompt return of an injured or medically disabled crew member, which constitutes sufficient reason for the emergency capability. Additional justification includes conditions that might render space station unhabitable (for example, by debris/meteoroid impact or contamination).

A Change Request to Level I has been proposed by the Office of the Associate Administrator for Safety, Reliability, Maintainability, and Quality Assurance (SRM&QA), Code Q. The response to date has been to allow the Office of Space Flight, Code M, to define the requirement, and design and implement the system. Code M is scheduled to issue a request for proposal (RFP) for a study to define crew rescue methods during FY 89.

3. Extra-Vehicular Activities (EVA)-Space Suits

OPEN ITEM: EVA/Space Suits for Space Station

STATUS: NASA is developing a space station optimized suit that will be operational when Permanent Manned Capability (PMC) is achieved. During the space station assembly and during the man-tended phase of operations, the crew will function from the Space Shuttle. The crew will use the current Space Shuttle suit that has better glove mobility than is afforded by the newer high pressure glove as currently designed. Also, the prebreathing issue raised in the previous ASAP findings will be eliminated since it will not be a requirement when the Orbiter cabin pressure is lowered to 10.2 psi and the Shuttle 4.3 psi suit is used.

NASA believes that the proven Space Shuttle suit, with improvements and additional life certification tested as required, will be adequate to meet the time line for the erection of Space Station Freedom, and is a safer, more conservative alternative than a newly developed high pressure suit.

B. NASA Response to Panel Annual Report, March, 1988

E. AERONAUTICS

1. X-Wing Flight Test Program Structure

OPEN ITEM: X-Wing lessons learned regarding development of key technologies and structuring R&D programs.

STATUS: The program was a high-risk venture from the start, but one with potentially high payoffs. Significant technological challenges included the development of a fly-by-wire quadraplex flight control system, fabrication of large composite blades capable of withstanding temperatures up to 350 degrees Fahrenheit, and resolution of numerous stability and control issues associated with higher harmonics, hub moment feedback, stopped rotor aeroelastic stability, and circulation control aerodynamics.

The program prioritized schedule first, technical second, and cost third. The schedule priority was driven by the Defense Advanced Research Projects Agency, which took the responsibility for cost growth in the development program. Such a schedule-driven program forced the design to press ahead before the requirements were completely known, and led to redesign of work as the requirements become fully known. Had this not been the priority, then cost growth could have been minimized by detailed planning early in the program, progressing serially from preliminary design to detail design with a minimum of parallel effort and redesign due to late design changes.

The matrix staff structure, which brought extensive people resources in the pneumatic/propulsion area from Lewis Research Center and in the rotor area from the Naval Research Laboratory to aid the Ames Research Center project office, proved to be an excellent source of technical talent. However, had NASA had in place a strong in-house supporting research and technology program, the program success would have been greatly enhanced. The ground-based test program including a Propulsion System Test Bed, a hardware in-the-loop simulation, and scaled powered wind tunnel testing, provided an excellent means of identifying problems prior to flight test. Any remaining structural problems would have been encountered prior to flight using these test-beds. The greatest technical challenge to date and, therefore, the most cost growth, was in the flight control system and blowing control laws. A paper written for the 1989 American Helicopter Society Annual Forum entitled "RSRA/X-Wing Flight Control System Development: Lessons Learned" covers the problems of balancing program goals with technical goals, software- and hardware-related problems, safety issues, and system testing.

4. Aircraft Operations and Safety Management

OPEN ITEM: Aircraft Operations and Safety Management

STATUS: Aircraft Operations and Safety Management within NASA remains the responsibility of each level of aircraft management. The NASA Headquarters Safety Division, Code QS, has the responsibility of coordinating Safety, Reliability, Maintainability, and Quality Assurance (SRM&QA) requirements with regard to aviation safety. The Aircraft Management Office (AMO) is tasked with implementing the programs at NASA Headquarters and ensuring safety requirements are integrated into all NASA operations and activities. To this end, both the AMO and SRM&QA Offices have produced new NASA Management Instructions (NMIs) that state Headquarters policy guidance for aviation safety programs and responsibilities. These draft NMIs are undergoing final review within Headquarters and will be presented to the Intercenter Aircraft Operating Panel (IAOP) for final review. This should eliminate any confusion relating to how safety responsibilities are divided between AMO and SRM&QA.

C. AEROSPACE SAFETY ADVISORY PANEL ACTIVITIES
FEBRUARY 1989 - JANUARY 1990

FEBRUARY

8-10 - Aerospace Medical Advisory Committee, NASA Headquarters
14-15 - Risk Management Review, NASA Reston, VA

MARCH

27 - Liquid Hydrogen Tank Review, NASA Headquarters
28 - Annual Meeting with NASA Administrator, NASA Headquarters
30 - Weather Concerns Meeting, NASA Headquarters
31 - Office of Space Flight General Management Status Review

APRIL

3-5 - Advanced Manned Operations, Dallas, TX
11-12 - Space Station Power Systems Review, NASA Lewis Research Center, Cleveland, OH
11-13 - Space Station Safety Summit, NASA Kennedy Space Center, FL
13-14 - STS-30 Flight Readiness Review, NASA Kennedy Space Center, FL
19-20 - Allied Bendix Propulsion Meeting, Alexandria, VA
25-26 - Space Station Review, NASA Reston, VA
28-30 - Aerospace Medical Advisory Committee Meeting, NASA Headquarters

MAY

2-4 - Integrated Logistics Panel, Michoud, LA
2-4 - AIAA Annual Symposium, Crystal City, VA
11 - Senate Subcommittee Testimony (Sen. Gore), ASRM Washington, DC
23-25 - Intercenter Aircraft Operations Panel, Atlantic City, NJ
31-1 - Space Station Work Package #1 Review, NASA Marshall Space Flight Center, AL

JUNE

1 - Orbiter Logistics Support Review, NASA Headquarters
1-2 - Aerospace Medical Advisory Committee, NASA Headquarters
27 - Aircraft Meeting, NASA Dryden Flight Research Facility, CA
28-29 - OSF Program Directors Review, Shepardstown, WV

JULY

6-7 - Plenary Session, NASA Lewis Research Center, Cleveland, OH
10-12 - SAE 1989 Joint Propulsion Conference, Monterey, CA
17 - Space Shuttle Orbiter Mods Review, Rockwell International, Downey, CA
25-26 - STS-28 Flight Readiness Review, NASA Kennedy Space Center, FL
- STS/SS Computer Software Briefing, NASA Johnson Space Center, TX
26-27 - AIAA/NASA Maintainability of Aerospace Systems Symposium, Anaheim, CA
31-2 - Space Station Work Package #2, NASA Johnson Space Center, TX

AUGUST

3-4 - STS Processing and Space Station Activities, NASA Kennedy Space Center, FL
4-6 - STS-28 L-2 and L-1 Day Reviews, NASA Kennedy Space Center, FL
18 - STS Safety Enhancements, NASA Johnson Space Center, TX

SEPTEMBER

5-8 - NSTS PDMR and ASRM Level II Briefing, NASA Marshall Space Flight Center, AL
12-13 - X-29 Flight Readiness Review, NASA Dryden Flight Research Facility, CA
26-28 - Space Station Work Package #3, NASA Goddard Space Flight Center, MD
and
Discussions with Administrator/Deputy Administrator, ASRM Briefing and Congressional Hearing, NASA Headquarters

OCTOBER

2-3 - STS-34 FRR Galileo, NASA Kennedy Space Center, FL
10 - STS-34 L-2 Day Review, NASA Kennedy Space Center, FL
15-17 - Aerospace Medical Advisory Committee Meeting, NASA Headquarters

NOVEMBER

7 - Space Shuttle Orbiter(s) Briefing, Rockwell International, Downey, CA
8 - Space Station Work Packages #'s 2 and 4 Briefing
McDonnell Douglas, Huntington Beach, CA
9 - Space Shuttle Main Engine Briefing, Rocketdyne, Canogoa Park, CA
27 - Space Suits Discussion, NASA Johnson Space Center, TX
29 - Space Shuttle Solid Rocket Booster Project Status Review, National Research Council, Washington, DC

DECEMBER

1 - Space Station Reviews with Associate Administrator for Space Flight and Director, Space Station, NASA Headquarters
14-15 - Solid Rocket Motor Briefing and Plant Tour, Thiokol, Watsach, Utah; and Annual Report Review, Salt Lake City, Utah

JANUARY

11-12 - Propulsion Meeting, NASA Headquarters
24-25 - Annual Report Editing Committee Meeting, NASA Headquarters

For Further Information
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Washington, DC 20546

National
Aeronautics and
Space
Administration