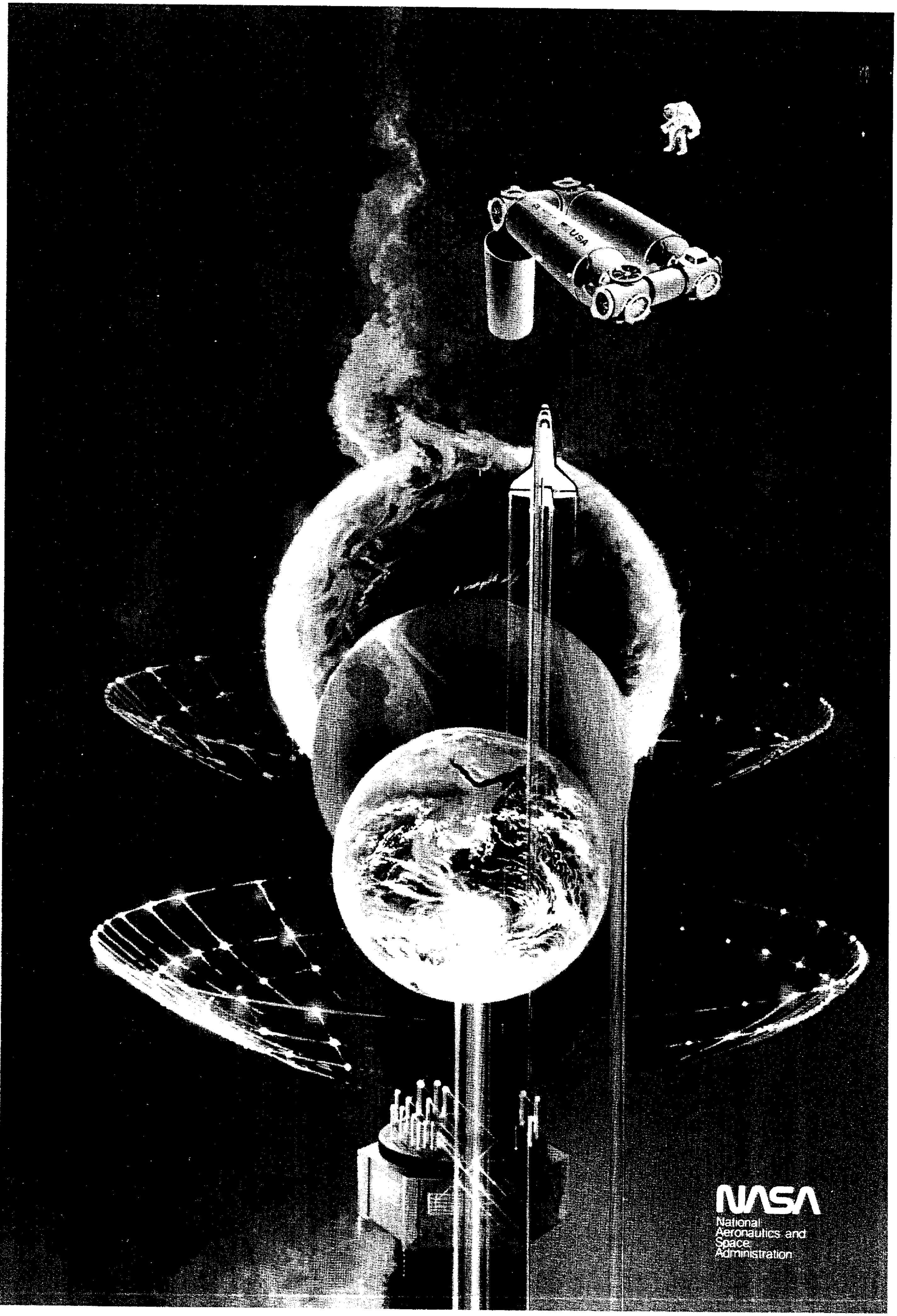
AEROSPACE SAFETY ADVISORY PANEL

ANNUAL REPORT MARCH 1990



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
Chairman
Aerospace Safety Advisory Panel

Enclosure

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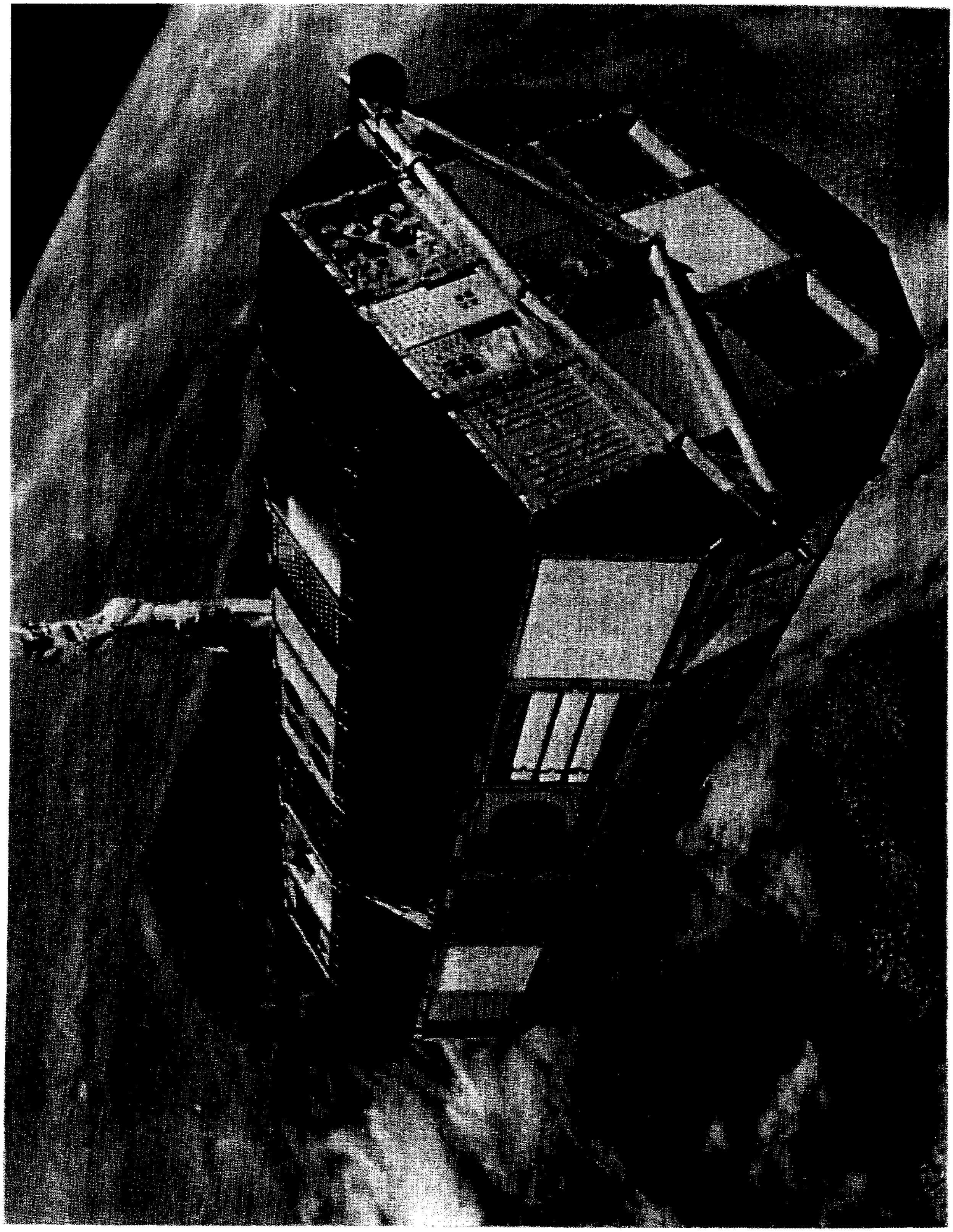


I. INTRODUCTION

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 firm plans to augment the Space Shuttle capability with an unmanned heavy-lift launcher (such as the Shuttle "C" vehicle).

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

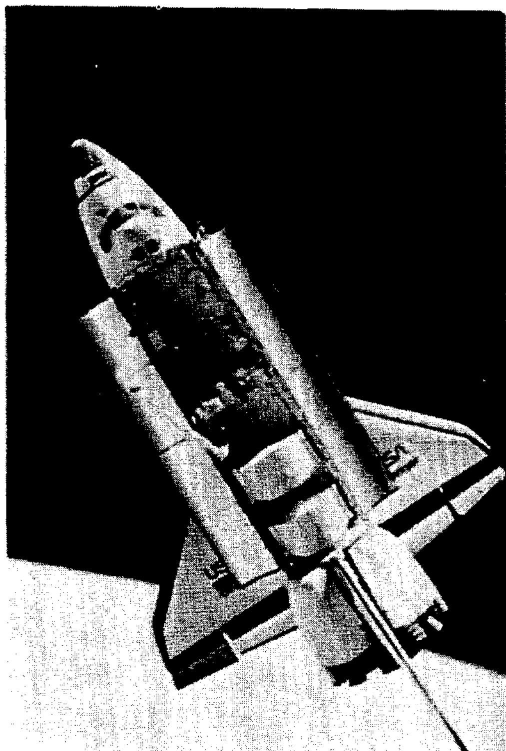
There has been one change to the makeup of the Panel during the previous year. Mr. Gerard W. Elverum, Jr., Vice President and General Manager, TRW Applied Technology Division, completed his service as a Panel member (1982-1989). Mr. Elverum is retained as a consultant to the Panel, thereby securing his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

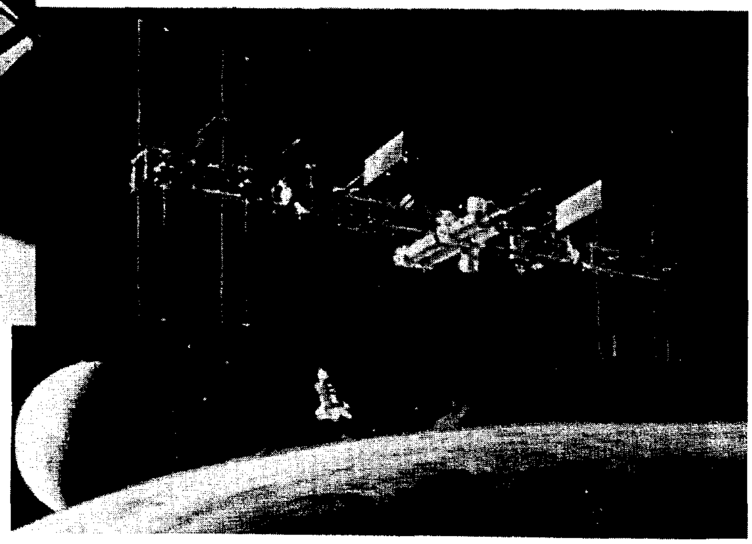
The Panel believes that it is worthwhile to restate its charter:

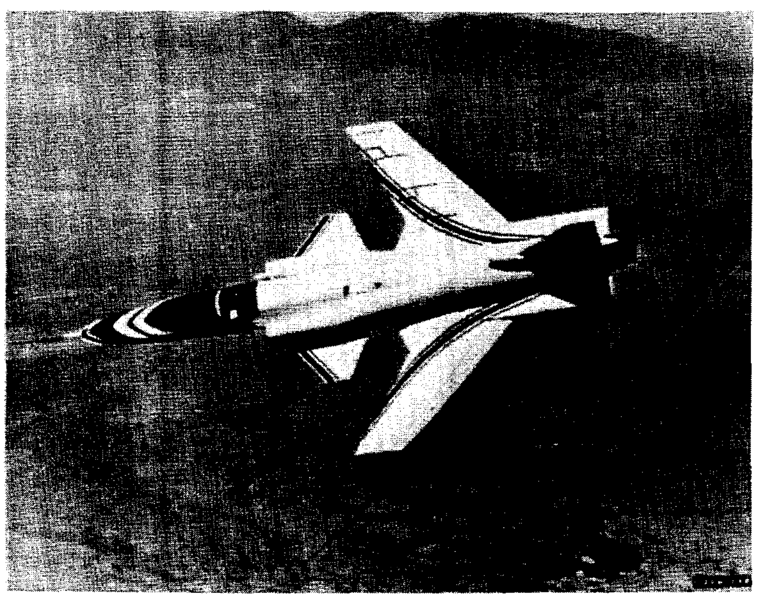
We are to advise the NASA Administrator and Congress on issues of safety throughout NASA. These safety issues encompass both systems and operational safety. To accomplish this advisory role we identify, review, and evaluate critical safety issues by means of direct fact-finding of both NASA and contractor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

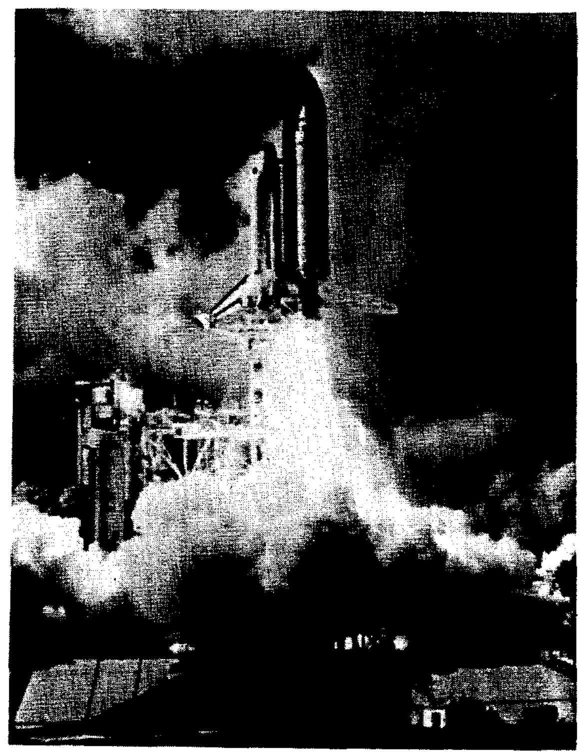
As advisors, we expect--and continue to have--access to all elements of NASA and appropriate areas of NASA contractors. Similarly, we expect that information on problem areas will continue to be provided voluntarily rather than having to be ferreted out by the Panel. The Panel does not have the number 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.

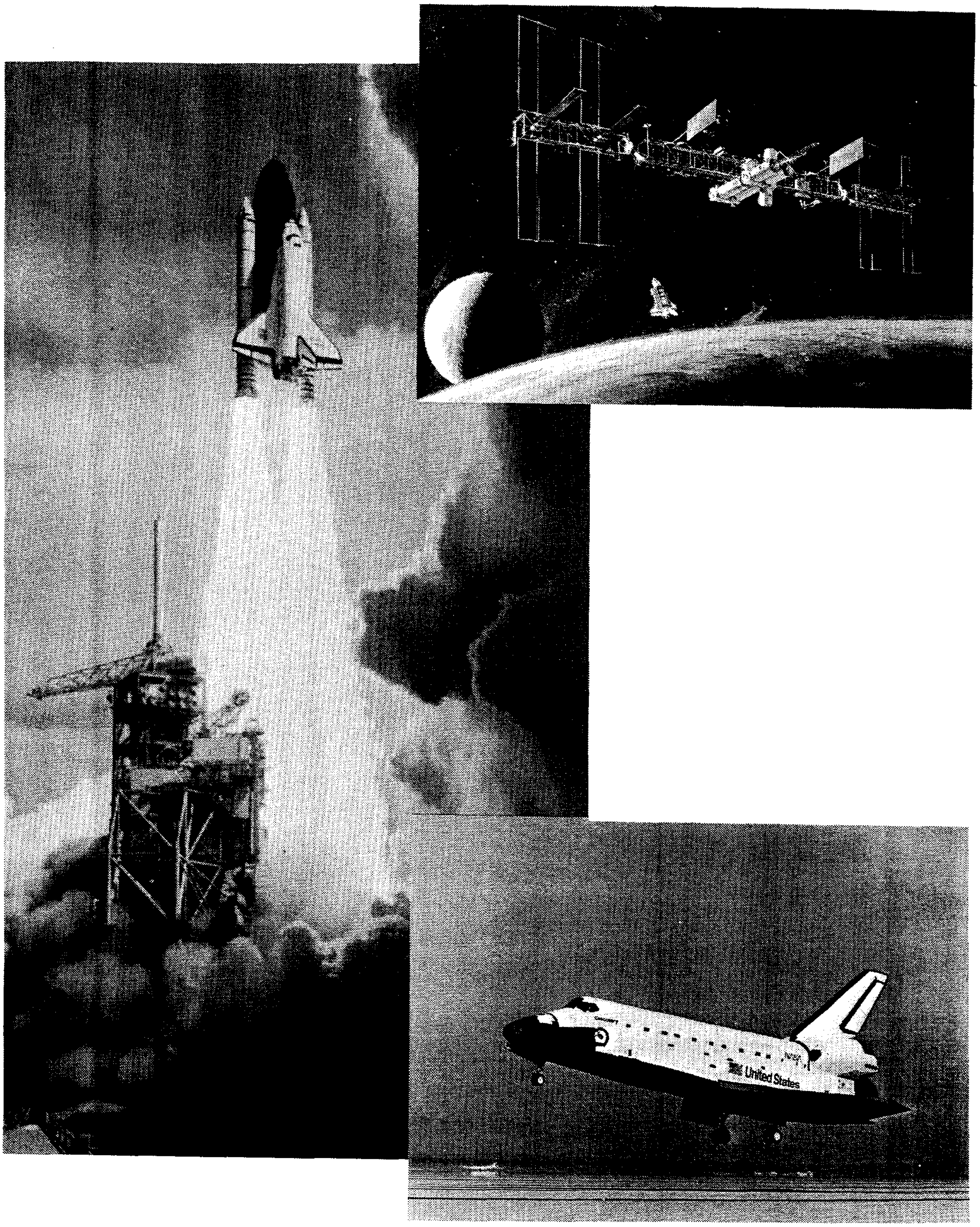
Recommendation #38: The NASA management should develop and adopt a policy with appropriate methodology for performing quantitative risk assessment at the outset of large space ventures such as the Space Station Freedom Program.

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

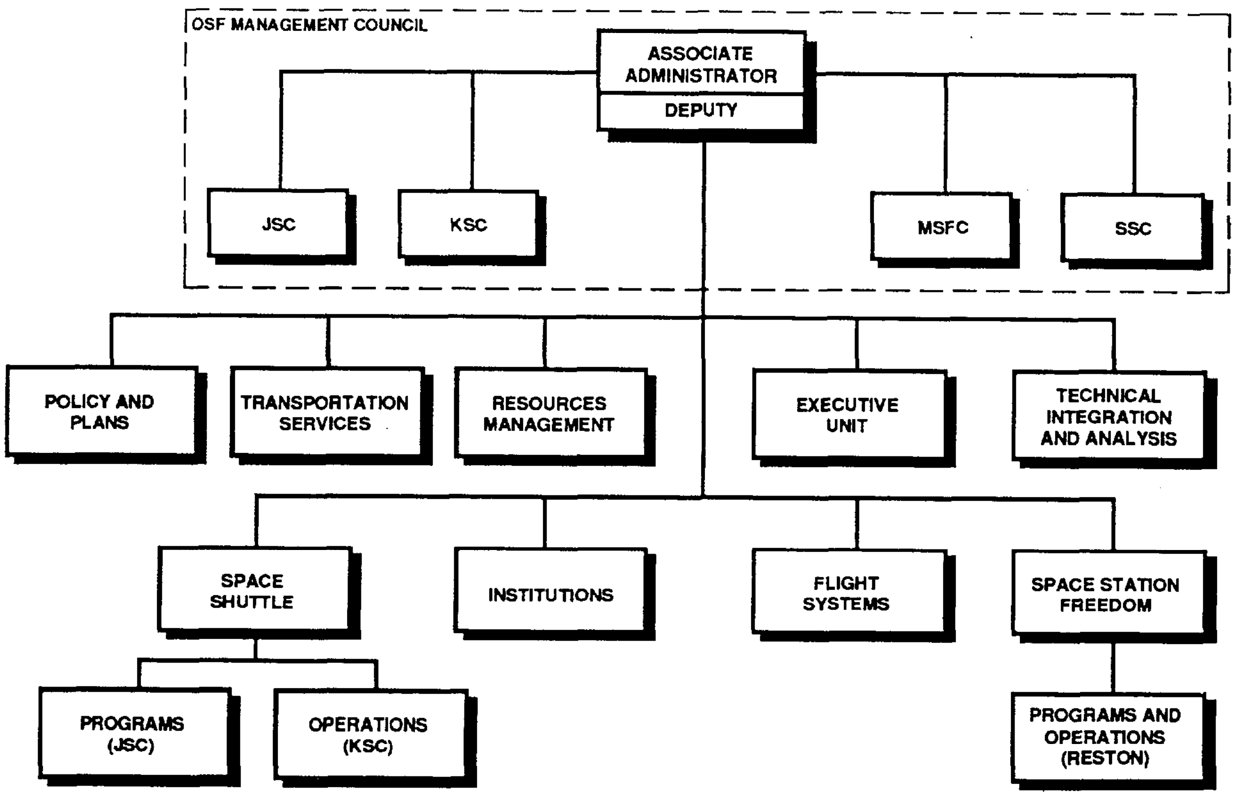


Figure 1, Office of Space Flight

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.

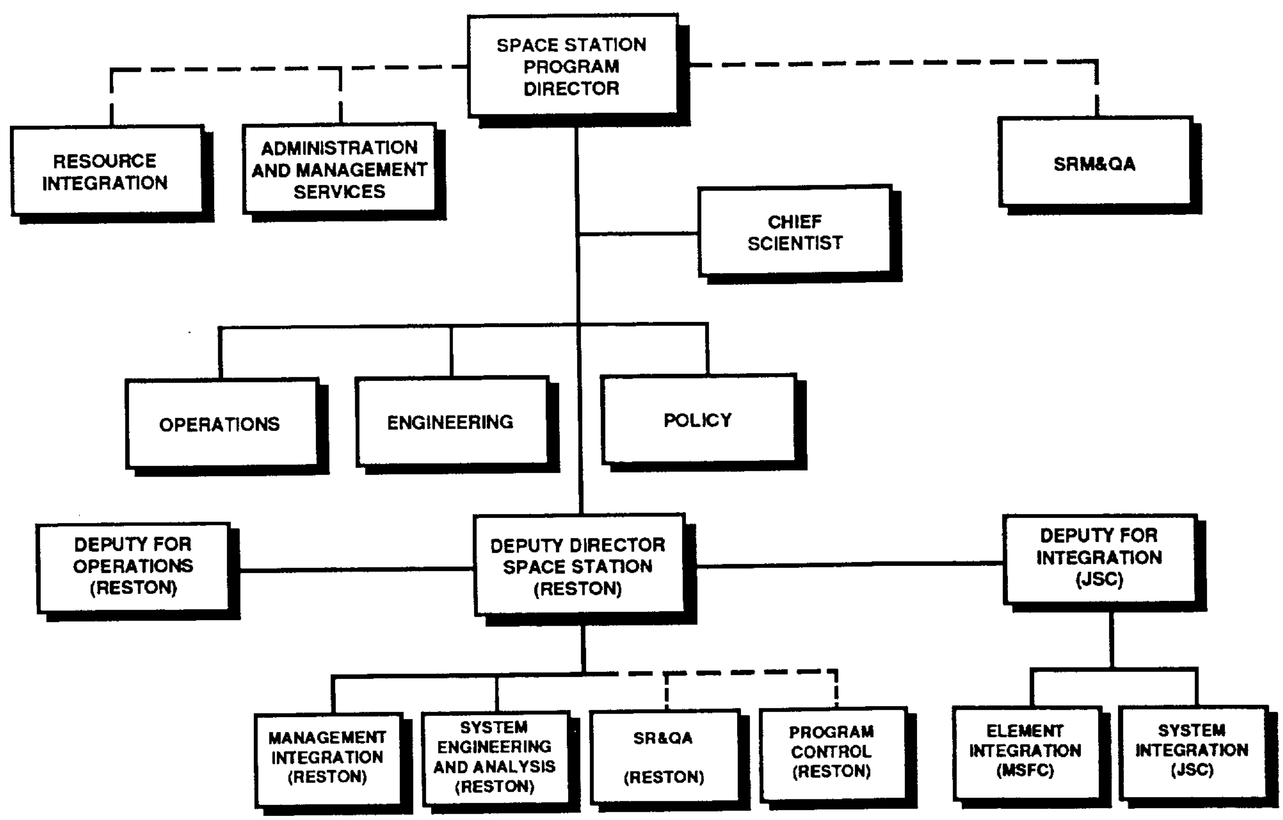


Figure 2, Space Station Freedom

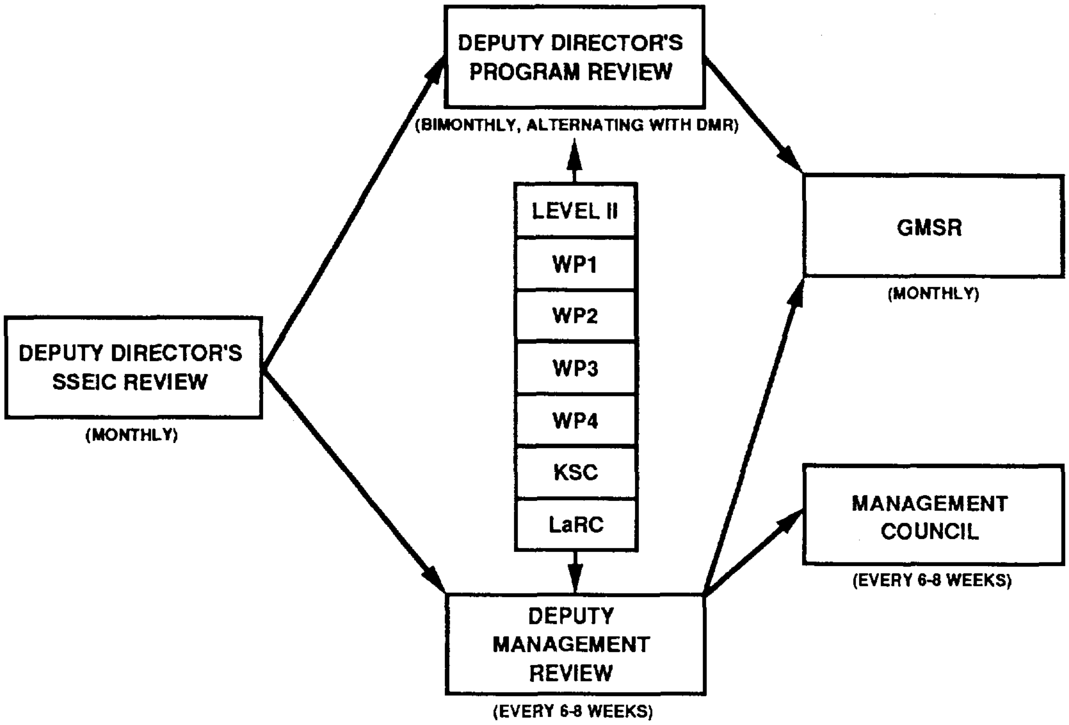


Figure 3, Space Station Freedom Program Review Plan

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.

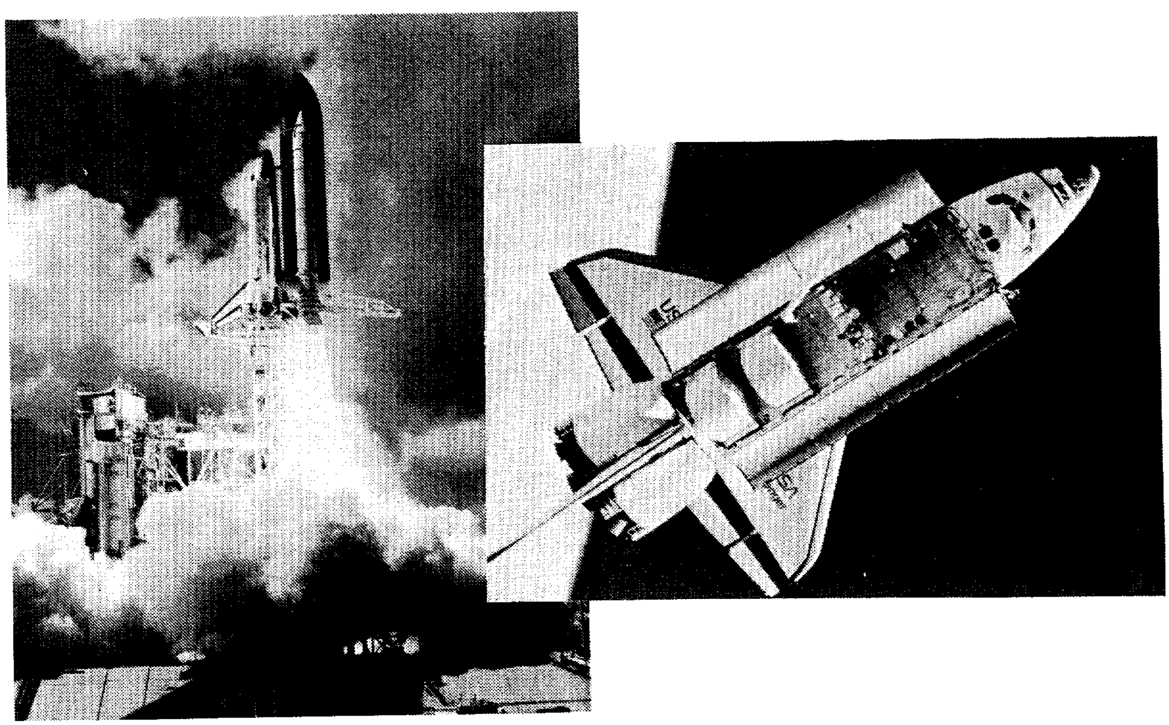
"Our panel's detailed reports to NASA contain a number of some specific recommendations for effective control and reduction of risk throughout the flight program.

"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

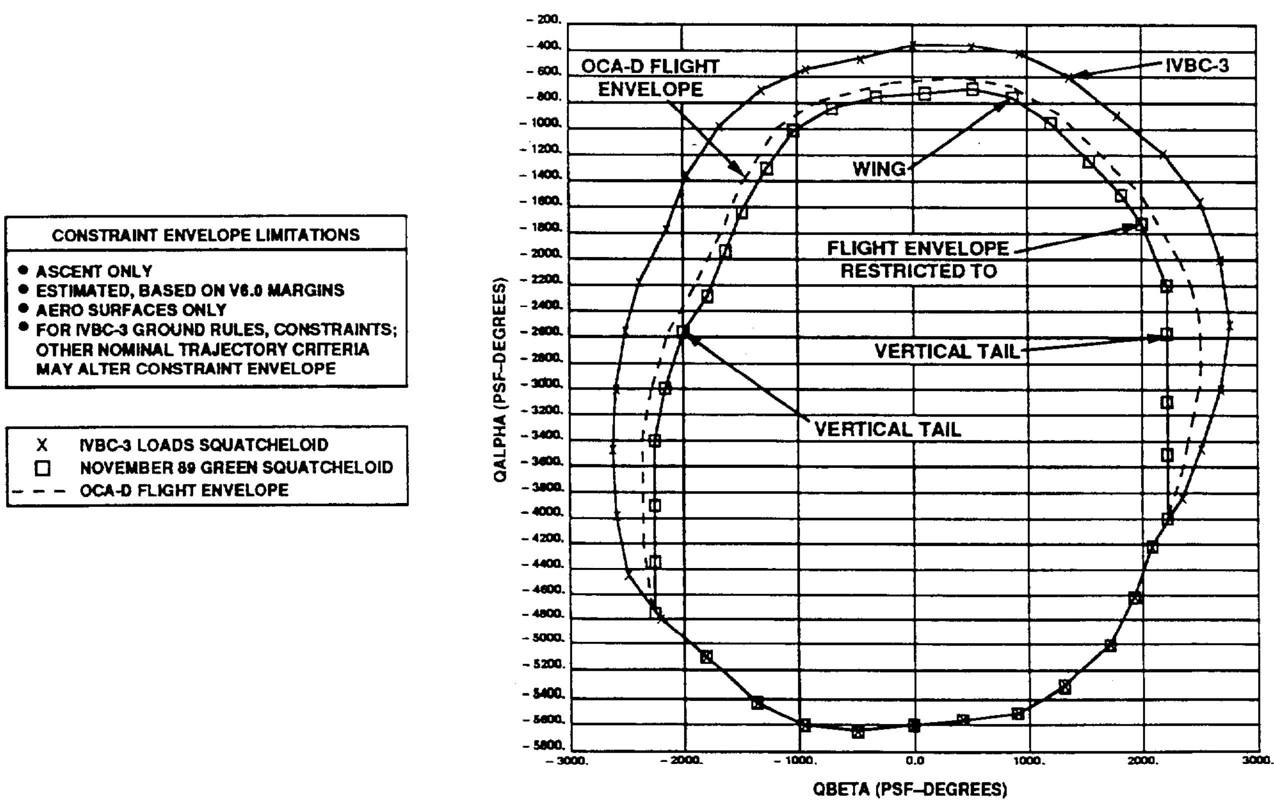


Figure 4A, MACH = 1.25
Restricted Green Squatcheloid and IVBC-3 Loads Squatcheloid

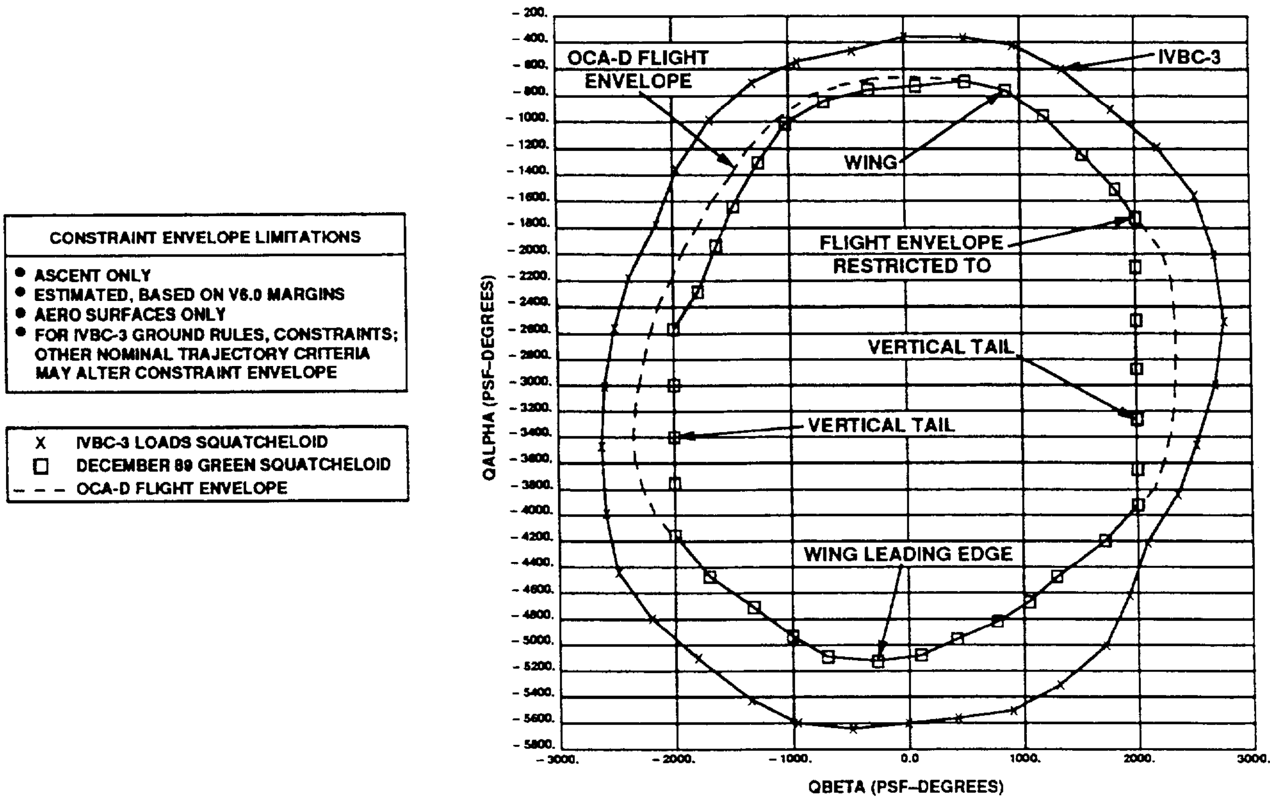


Figure 4B, MACH = 1.25
Restricted Green Squatcheloid and IVBC-3 Loads Squatcheloid

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.