

Annual Report March 1992

AEROSPACE  
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PANEL

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**NASA**

National Aeronautics and  
Space Administration



***Aerospace Safety  
Advisory Panel***

**Annual Report**

**March 1992**

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

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National Aeronautics and  
Space Administration

Washington, D.C.  
20546

Reply to Attn of: Q-1

March 1992

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

Dear Admiral Truly:

The Aerospace Safety Advisory Panel (ASAP) is again pleased to submit its Annual Report. This report covers the period from February 1991 through January 1992 and provides you with findings, recommendations, and supporting material. We ask you to respond only to Section II, "Findings and Recommendations."

During the past year, we have been gratified by the continued prudent approach NASA has shown with respect to Space Shuttle operations. We also are encouraged by the improvements we have seen, particularly in the area of Shuttle processing. Although more work needs to be done in this area, you certainly appear to be on the right track. We also view the revised Space Station Freedom Program as a welcome improvement and a realistic course to follow.

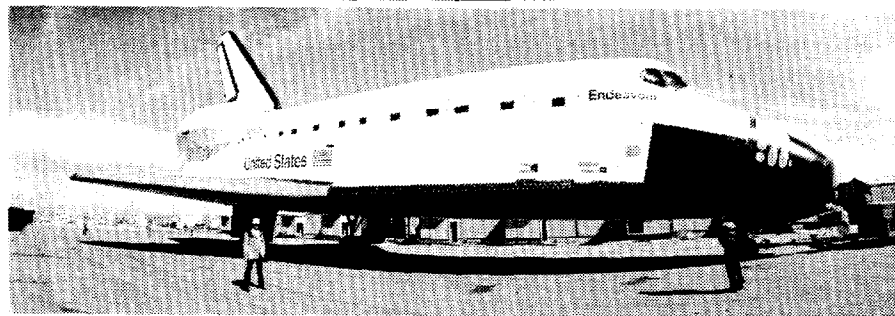
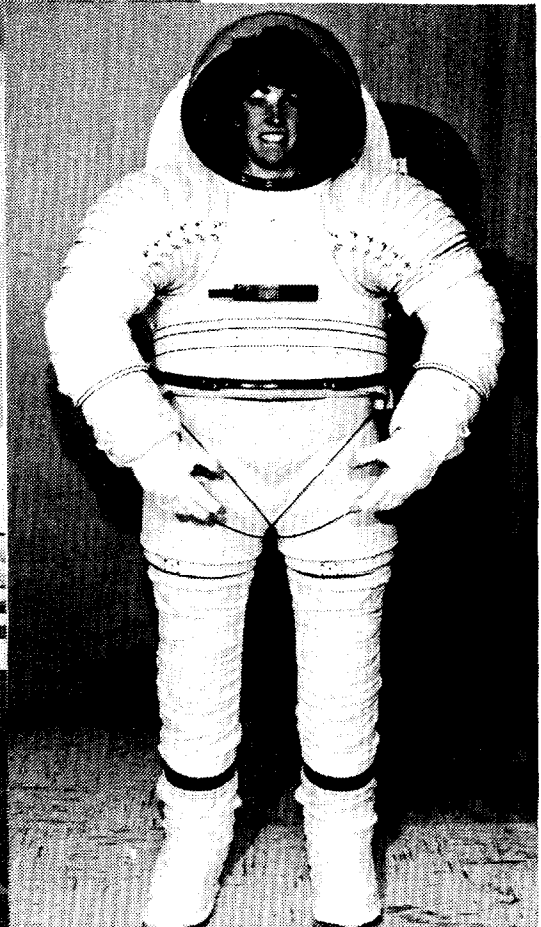
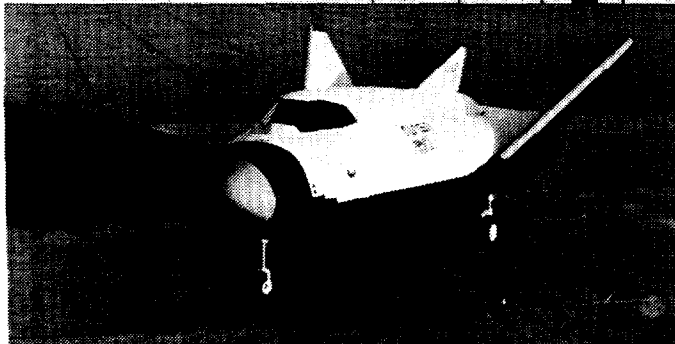
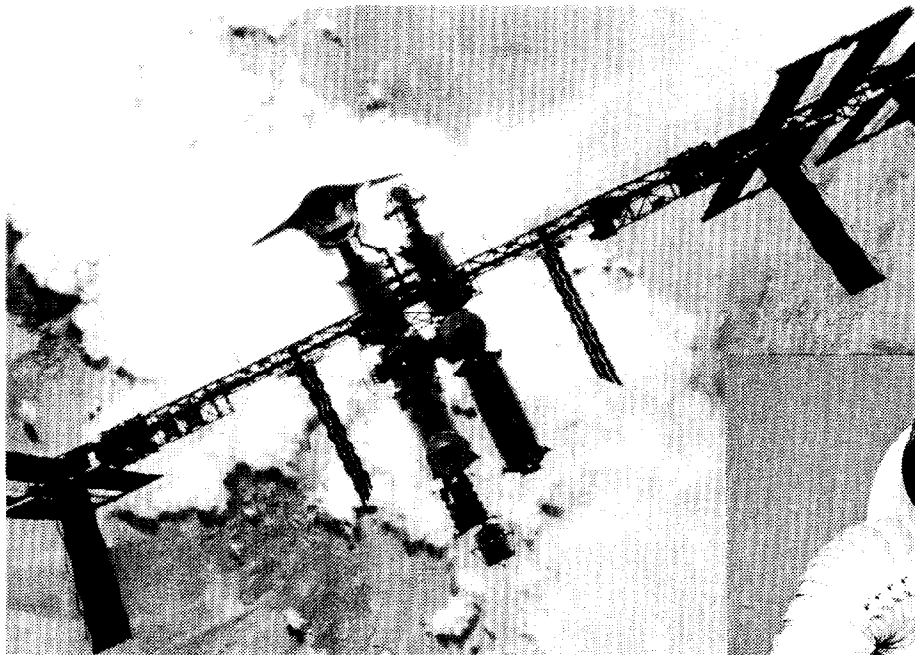
In spite of these gains, however, we are distressed by the actions taken with respect to the Space Shuttle Main Engine (SSME). In particular, we disagree with the decision to cancel the development of the hydrogen alternate turbopump and large throat main combustion chamber. It is the Panel's consensus that improvements such as these are indispensable to the safe continuation of the Space Shuttle Program for the next 20 to 30 years and would contribute more to safety and reliability than any other identified propulsion improvement. In fact, we consider a comprehensive and continuing program of safety and reliability improvements in all areas of Space Shuttle hardware and software to be an essential component of maintaining successful operations. As a safety advisory panel, we cannot support the elimination of important safety and reliability improvements and urge you to reconsider the advanced turbopump and large throat main combustion chamber projects.

Very truly yours,

Norman R. Parmet  
Chairman  
Aerospace Safety Advisory Panel

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## I. INTRODUCTION

# I

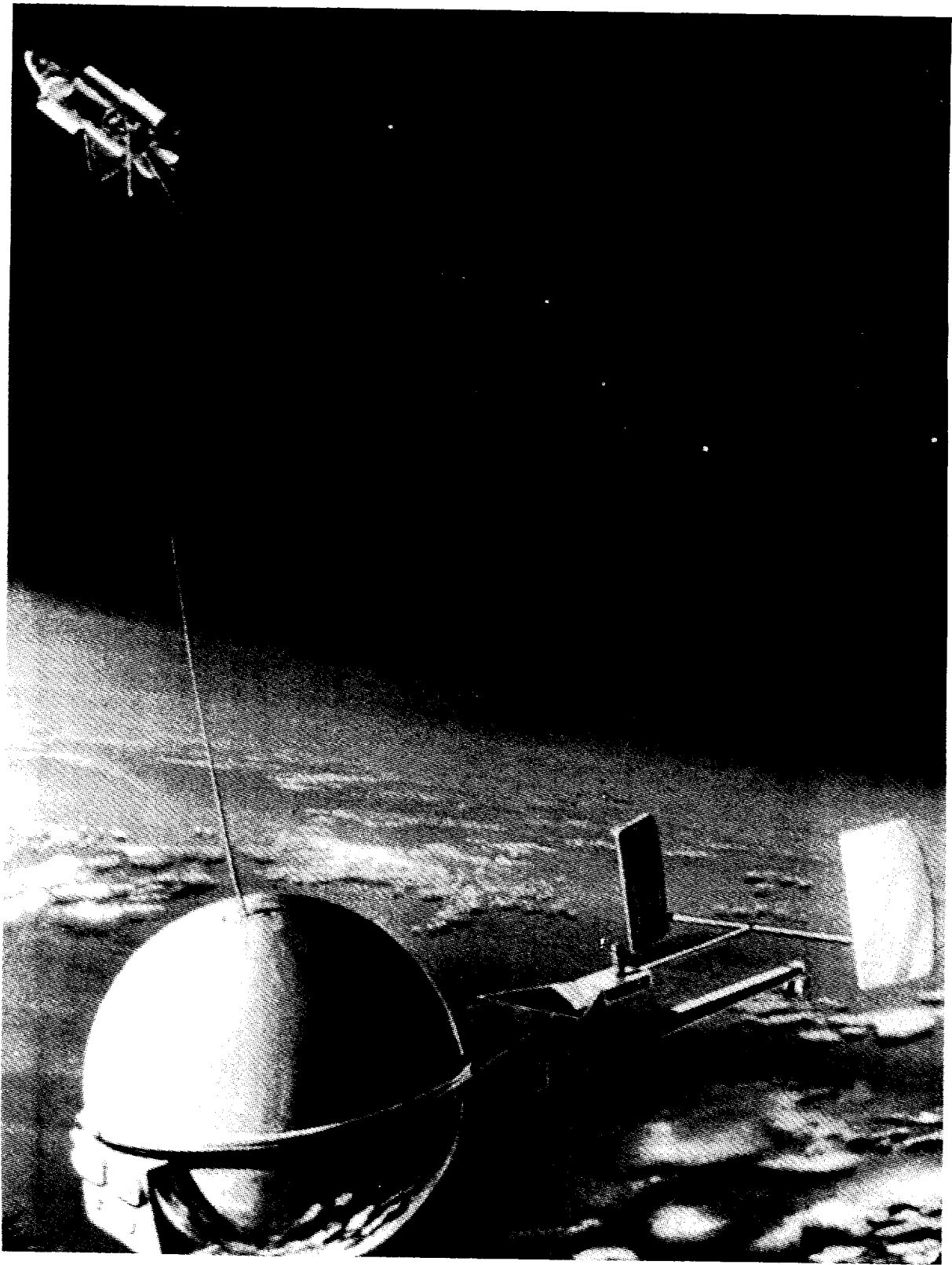
## INTRODUCTION

In 1991, NASA continued successful Space Shuttle flights and restructured the Space Station Freedom Program (SSFP) with a downsized design. This design involved significantly lower technological and operational risks than the earlier versions. The Aerospace Safety Advisory Panel (ASAP) monitored these activities as well as NASA's aeronautical programs at NASA installations and contractor facilities. Specific topics that were examined in-depth by the Panel included Space Station organization, Space Shuttle structures, Space Shuttle processing, design and manufacturing plans for the Advanced Solid Rocket Motor (ASRM), Space Shuttle landing performance and the need for an operational autoland capability, Space Shuttle logistics, loads and overhaul plans, and aeronautical flight research programs.

The results of the Panel's activities are presented, as in previous years, in a set of findings and recommendations, which are in Section II of this report. Section III is composed of "Information in Support of Findings and Recommendations." Appendices in Section IV provide a listing of Panel members, the NASA response to the findings and recommendations contained in last year's report, and a chronology of the Panel's activities during the reporting period.

This report highlights both improvements in NASA's safety and reliability activities and specific areas where additional gains might be realized. One area of particular concern involves the curtailment or elimination of Space Shuttle safety and reliability enhancements; it is addressed by several findings and recommendations. The Panel considers this essential to the continued successful operation of the Space Shuttle. Therefore, it is recommended herein that a comprehensive and continuing program of safety and reliability improvements in all areas of Space Shuttle hardware/software be considered an inherent component of ongoing Space Shuttle operations.

During 1991, Joseph F. Sutter retired from the Panel after serving as its Chairman and, most recently, as a consultant to it. Paul M. Johnstone and John A. Gorham joined the Panel as consultants.



## **II. FINDINGS AND RECOMMENDATIONS**

## II

# FINDINGS AND RECOMMENDATIONS

### A. SPACE STATION FREEDOM PROGRAM

**Finding #1:** During the past 1½ years, Space Station Freedom (SSF) has undergone a reconfiguration involving many technical changes and program deferrals. These changes were highlighted in the Aerospace Safety Advisory Panel's (ASAP's) March 1991 report. Some of the changes affect risk and safety while others influence serviceability and usefulness. Nevertheless, the SSF design that has emerged is more realistic and capable of supporting a stable development program.

**Recommendation #1:** Safety and risk considerations should remain of paramount importance in the development of the reconfigured Space Station.

**Finding #2:** The ASAP March 1991 Annual Report characterized the Space Station Freedom Program (SSFP) as plagued with technical and managerial difficulties and lacking an effective systems engineering and integration organization. Significant developments have occurred in the ensuing year. In particular, there has been a clarification of system engineering and systems integration responsibilities among NASA Headquarters and the Centers. Also, key managerial assignments have been delegated to appropriate Centers. The new arrangement benefits the program by drawing on the substantial technical expertise of the Centers' staff members not specifically assigned to the SSFP.

**Recommendation #2:** The changes introduced in the systems engineering and integration management areas should be monitored to ensure that the new arrangement is effective and that maximum use is made of each Center's particular capabilities.

**Finding #3:** NASA's current policy is not to leave a crew on the Space Station without an attached Space Shuttle or other assured return capability. At present, there is no program to develop a dedicated assured return vehicle. However, using an Orbiter as an assured return vehicle on long-duration missions reduces the number of Space Shuttles available for other purposes and raises potential safety and reliability issues.

**Recommendation #3:** NASA should continue studies to explore various options for assuring a safe return capability from SSF leading to the selection of a preferred option in a timely manner.

**Finding #4:** Use of preintegrated truss (PIT) sections for SSF greatly simplifies on-orbit assembly. However, the capture latch, guide pins, and motorized bolts used to couple the assemblies may not always be in proper alignment. This could lead to damaging the guide pins or bolts thereby precluding mating.

**Recommendation #4:** The PIT development program should consider actual hardware tests to verify the



assembly process to be used in orbit. These tests should encompass the full range of misalignments, tolerances, and impacts that might reasonably be expected to occur when the truss is assembled with the actual equipment and procedures to be used.

**Finding #5:** Software for the Data Management System (DMS) represents one of the major challenges to meeting the intensive delta design review (DDR) schedule.

**Recommendation #5:** The DMS software development process should be monitored closely to ensure it is compatible with the existing DDR schedules.

## B. SPACE SHUTTLE PROGRAM

### ORBITER

**Finding #6:** The results of flight tests indicate that the turbulent flow over the body flap creates a spectrum of hinge moments greater than that used in the original structural fatigue analysis. It also has been determined that an additional load path exists from the flap to the supporting structure. Further, the flap actuators were found to be more flexible than originally assumed. Additional tests are to be conducted to evaluate hinge moments and actuator flexibility.

**Recommendation #6:** NASA should evaluate, as rapidly as possible, the results of the new tests and loads analyses to reestablish the allowable number of flights for the body flap.

**Finding #7:** NASA has developed a Shuttle Modal Inspection System (SMIS) for detecting changes in stiffness in structural/mechanical systems due to factors such as wear or cracking. The SMIS has shown good results when used on the Orbiter body flap and elevon systems (including actuators and supporting structures). However, it is not a complete replacement for more conventional nondestructive inspection (NDI) methods. These conventional methods are capable of detecting cracks in primary structures with a "critical crack length" too small to cause a detectable change in stiffness and hence be measurable by SMIS.

**Recommendation #7:** The SMIS procedure should be used only to augment more conventional NDI methods.

**Finding #8:** Thermal protection system tiles are inspected for damage after every flight by specially trained and highly experienced inspectors using tactile techniques. These inspectors determine if the tiles are loose and help to identify problems in step and gap. The current procedure is largely qualitative and highly dependent on the skill of the individual inspectors.

**Recommendation #8:** A program to select and train new inspectors should be instituted to ensure the availability of an adequate cadre of qualified inspectors throughout the life of the Orbiters. In addition, further effort should be applied to the development of a quantitative inspection technique.

**Finding #9:** The Space Shuttle Program requires both turnaround and periodic major Orbiter overhaul functions.

**Recommendation #9:** Overhaul and major modification efforts should be organizationally and functionally separated from routine turnaround operations because of the different types of planning and management skills and experience required.

**Finding #10:** The Space Shuttle design presently includes an automatic approach guidance system that requires crew participation and does not control all landing functions through touchdown and rollout to wheel stop. The present system never has been flight tested to touchdown, but a detailed test objective for such a test is in preparation. The availability of a certified automatic landing system would provide risk reduction benefits in situations such as weather problems after de-orbit and Orbiter windshield damage.

**Recommendation #10:** Future mission plans suggest the potential for significant risk reduction if the present Space Shuttle automatic landing capabilities are fully developed and certified for operational use. System development should include consideration of hardware, software, and human factors issues.

**Finding #11:** NASA continued its software independent verification and validation (IV&V) activities during the year. This independent review has demonstrated its value by finding failure modes that previously were unknown. The Safety and Mission Quality organization has taken on greater responsibilities for software safety.

**Recommendation #11:** NASA should continue to support a software IV&V oversight activity. The present process should be reviewed to ascertain whether it can be streamlined. The IV&V oversight activity should include the development of detailed procedures for test generation. NASA should not

attempt to duplicate, through IV&V or otherwise, the actual performance of all verification and validation tests.

**Finding #12:** The new Space Shuttle general purpose computer (GPC) apparently has performed well. The Single Event Upsets (SEUs) were no more numerous than expected. Based upon NASA's model of SEUs, the accuracy of the predictions is excellent, and supports NASA's estimate that the probability of an SEU-induced failure is negligibly small. Nevertheless, there still is concern about the eventual saturation of usable memory on the GPC.

**Recommendation #12:** NASA should initiate a small study on alternatives for future GPC upgrades and/or replacements. This should involve other NASA organizations that have been studying computer evolution.

**Finding #13:** The replacement of some requested software upgrades with crew procedures is a matter of serious concern particularly when the functions addressed could be handled with greater reliability and safety by software. The crew already has to cope with a very large number of procedures.

**Recommendation #13:** NASA should conduct a thorough review of all crew procedures that might be performed by the computer system to determine whether they are better done manually by the crew or by the software. Human factors specialists and astronauts should participate.

## **SPACE SHUTTLE MAIN ENGINES (SSME)**

**Finding #14:** There are currently a sufficient number of flightworthy engines to provide each Orbiter with a flight set as well as provide an adequate number of spares.

**Recommendation #14:** Maintain this position.

**Finding #15:** The SSME component reliability and safety improvement program, designed to enhance or sustain the current component operating margins, has made progress towards achieving its objectives. The high-pressure fuel turbopump (HPFTP) has completed its certification. Changes to the two-duct powerhead have eliminated injector erosion, but more work is needed to reduce main combustion chamber (MCC) wall damage. The process for producing the single-tube heat exchanger has been developed, and heat exchangers are being installed for testing. The high-pressure oxygen turbopump (HPOTP) changes were less successful in meeting service-life objectives, but an operational workaround to reduce turnaround time for the HPOTP has been implemented.

**Recommendation #15:** Continue the development of these reliability and safety improvements. Complete their certification as expeditiously as possible.

**Finding #16:** The development of the large throat main combustion chamber (LTMCC) and Advanced Fabrication Processes for the SSME have been discontinued. Both of these efforts eventually would have led to significantly enhanced safety and reliability of the SSME.

**Recommendation #16:** Restore these important safety-related programs.

**Finding #17:** The Alternate Turbopump Program has made major progress toward achieving its objectives despite design problems uncovered during design verification systems (DVS) and component development tests. Engine-level tests have begun for both turbopumps. The value of heavily instrumented test items run on the E-8 component test stand has been demonstrated clearly, as evidenced by the rapid identification of problem sources and the development of design changes to overcome them. NASA has opted to delete the work on the alternate HPFTP and to continue only the development on the alternate HPOTP with the intent to use it, when certified, in conjunction with the current HPFTP. While such a configuration is feasible, such usage will not achieve the increase of operating margins in the engine system to the levels desired and advocated by program and propulsion specialists.

**Recommendation #17:** Restore the alternate HPFTP development.

## **SOLID ROCKET MOTORS**

**Finding #18:** NASA previously has investigated the possibility of developing a new, low-temperature elastomeric O-ring material to eliminate the need for the field joint heater assembly on the Redesigned Solid Rocket Motor (RSRM). None was found that was compatible with the grease used during assembly. The material (GCT Viton) being developed for the Advanced Solid Rocket Motor (ASRM) O-rings has proper elasticity down to 33 °F.

**Recommendation #18:** NASA should evaluate the ASRM O-ring material (GCT Viton) for use on the RSRM to eliminate the field joint heaters and their installation.

**Finding #19:** The full-scale ASRM propellant manufacturing facility may not be directly scaleable from the continuous mix pilot plant. Particular problem areas relate to the particle size of the propellant and the screw pump section of the rotofeed.

**Recommendation #19:** Scale-up of the ASRM propellant manufacturing plant should be scrutinized closely by NASA to ensure that safety and schedule are not compromised.

**Finding #20:** An ambitious automated process is planned for the ASRM propellant mixing and casting. This process will be largely computer-operated with human operators serving primarily as initiators and monitors. This will place significant demands on the design of the operator interface of the system to ensure an effective and safe allocation of tasks and responsibilities between humans and computers.

**Recommendation #20:** The ASRM program should develop task and functional analyses of the human operator's role in the solid rocket manufacturing process and the operator interface with the computer system with emphasis on safety aspects.

**Finding #21:** Development of the ASRM case and its manufacturing processes includes a number of new methods and materials. For example, a new steel case material with associated plasma-arc welding and repair

techniques and automated internal stripwinding of the insulation are part of the design.

**Recommendation #21:** Due to the extensive use of new materials and processes in ASRM case manufacturing, NASA should monitor the associated development test program carefully to ensure that safety is not compromised.

**Finding #22:** NASA has decided not to improve the current aft skirt design to meet the original design specification of a factor of safety of 1.4. NASA now believes that a 1.28 factor of safety is adequate because the loads are well-defined.

**Recommendation #22:** Due to the lower factor of safety on the current RSRM skirts and the planned use of the same skirt on future ASRMs, NASA should task its safety organization to monitor the loads/strains measured during launches to establish a truly credible data base for the statistical justification of the lower factor of safety.

**Finding #23:** Logistics development for the ASRM is being pursued. All related major contractors and NASA groups are actively participating. Planning documents for support equipment, training, and transporting the motor elements are being prepared.

**Recommendation #23:** Continue the early and thorough consideration of ASRM logistics issues.

## **LAUNCH AND LANDING**

**Finding #24:** Several landing anomalies were experienced during the past year, including an extremely short landing on STS-37. Careful examination of the

causes of these anomalies led to significant operational improvements.

**Recommendation #24:** A continuing analysis of landing performance should be undertaken to include hardware, software, personnel functions, and information transfer. Continued improvement in all areas related to landing safety, including use of wind data and automatic guidance, should be sought as part of the movement to shift more landings to the Kennedy Space Center (KSC).

**Finding #25:** In spite of significant advances over the past year, there is still a need to improve the effectiveness of launch processing at KSC. It is rare when a vehicle is taken to the pad and launched without delays. Subsystem problems sometimes either require rolling the vehicle back to the Vehicle Assembly Building (VAB) or they cause delays at the pad.

**Recommendation #25:** Continue efforts to improve the effectiveness of launch processing operations. Each occurrence of a problem at the pad should be reviewed to determine why it was not caught in the VAB or Orbiter Processing Facility.

**Finding #26:** Morale among launch processing personnel at KSC improved over the past year. This most likely is the result of a heightened sense of individual responsibility, improved systems training, and a better supervisory/management approach.

**Recommendation #26:** Continue and expand the approaches that have been successful over the past year.

**Finding #27:** Operations and maintenance instructions (OMIs) have shown improvement. However, recent over-pressurization of a solid rocket booster (SRB) hydraulic tank has been attributed to an improperly written OMI. It also has been noted that an apparent excess of signatures still is needed in the paperwork generation and revision process.

**Recommendation #27:** Effort should be continued to improve the quality of OMIs. This should include the generation, review, and revision of the instructions. Efforts also should be made to reduce unnecessary signature requirements and consolidate paperwork systems.

**Finding #28:** The use of task teams at KSC appears to be working well.

**Recommendation #28:** The task team approach should be expanded as planned. In addition, coordination among task teams should be improved.

**Finding #29:** Procedures for tracking, analyzing, and providing corrective action for hardware problems arising at KSC are complex and lengthy involving numerous entities. There is no overall coordination effort to ensure that appropriate corrective action is taken.

**Recommendation #29:** The Space Shuttle Program should establish a coordinating function that is responsible for ensuring that proper and timely action is taken by responsible organizations in correcting problems that occur during launch preparation.

**Finding #30:** The Shuttle Processing Data Management System II (SPDMS II) has not yet provided many of its anticipated benefits. This may be because prospective users have not been fully involved in its design. Various temporary subsystems have emerged and are being used. However, these may be difficult to integrate into the final design.

**Recommendation #30:** Designers of the SPDMS II system should directly involve users in the system's design and implementation. In particular, care should be exercised to ensure that the various subsystems now being used successfully are included in the final design.

#### **LOGISTICS AND SUPPORT**

**Finding #31:** The Orbiter logistics and support program appears to be exhibiting a steady trend of improvement. The component overhaul and repair facility has been enhanced, and personnel skills have been upgraded. This has improved the control of such issues as cannibalization, serviceable component spares levels, and replenishment of spares stocks. However, support of Orbiter OV-105 (Endeavour) has caused extra effort in the latter months of the year and undoubtedly will continue to do so in 1992.

**Recommendation #31:** This excellent program should be continued with particular attention on the possible impacts of servicing OV-105.

**Finding #32:** Coordination among NASA Centers and contractors on logistics and support is excellent. This is due in large part to the activities of

the Integrated Logistics Panel (ILP), which meets at various locations at approximately 4-month intervals.

**Recommendation #32:** NASA should continue to support the excellent work being performed by the ILP.

**Finding #33:** Transfer of critical management skills and authority to the NASA Shuttle Logistics Depot (NSLD) and to KSC under the Logistics Management Responsibility Transfer (LMRT) Program is continuing. However, in some instances, funding limitations are slowing the process. Memoranda of Agreement (MOA) documents that establish details of transfer arrangements between such Centers as the Johnson Space Center (JSC), Marshall Space Flight Center (MSFC), and KSC are being revised or finalized.

**Recommendation #33:** It is important that the centralization of authority and equipment at KSC continues as planned under the LMRT concept.

**Finding #34:** NSLD is consolidating its activities at Cocoa Beach and is having a positive effect upon the critical issue of repair turn-around time (RTAT) for line replaceable units (LRUs). It provides protection against threats of unavailability of repaired or overhauled units in many cases in which the original manufacturers are no longer providing support. RTAT data support the importance of the proximity of the NSLD facilities to KSC.

**Recommendation #34:** The NSLD is essential to the efficient support of the Space Shuttle fleet and should continue to be supported at its current level.

**Finding #35:** Cannibalization (or the removal of working components from an Orbiter to meet shortages in another vehicle) has been the subject of much management attention. With a few persistent exceptions such as auxiliary power units (APUs), cannibalization rates now have been reduced to a commendably low level.

**Recommendation #35:** Maintain rigid controls on cannibalization. This will be particularly important to accommodate the absorption of OV-105 into the operating fleet next year.

**Finding #36:** The reduction of component RTAT has been subjected to as much management scrutiny as cannibalization and has, perhaps, an even greater economic and support effect upon Orbiter capability.

**Recommendation #36:** There can be no relaxation of the vigilance entailed in the pursuit of this cost-sensitive problem. Therefore, continue to keep the tightest control over the RTAT problem.

**Finding #37:** The problem of stock inventory held at or below minimum established levels is becoming critical. This is largely due to introduction of OV-105 and to major modification programs to other Orbiters.

**Recommendation #37:** Establish stocking recovery programs as soon as possible.

**Finding #38:** The problem of providing replacements or substitutes for parts or components that are now out of production will inevitably worsen with each passing year. In many cases, original equipment manufacturers (OEMs) are unwilling or unable to regenerate small batch production.

**Recommendation #38:** It is essential to try to anticipate potential shortages before they impact the program. Although this problem currently is being addressed by NASA, increased management pressure is needed to avoid a potential launch rate problem in the future.



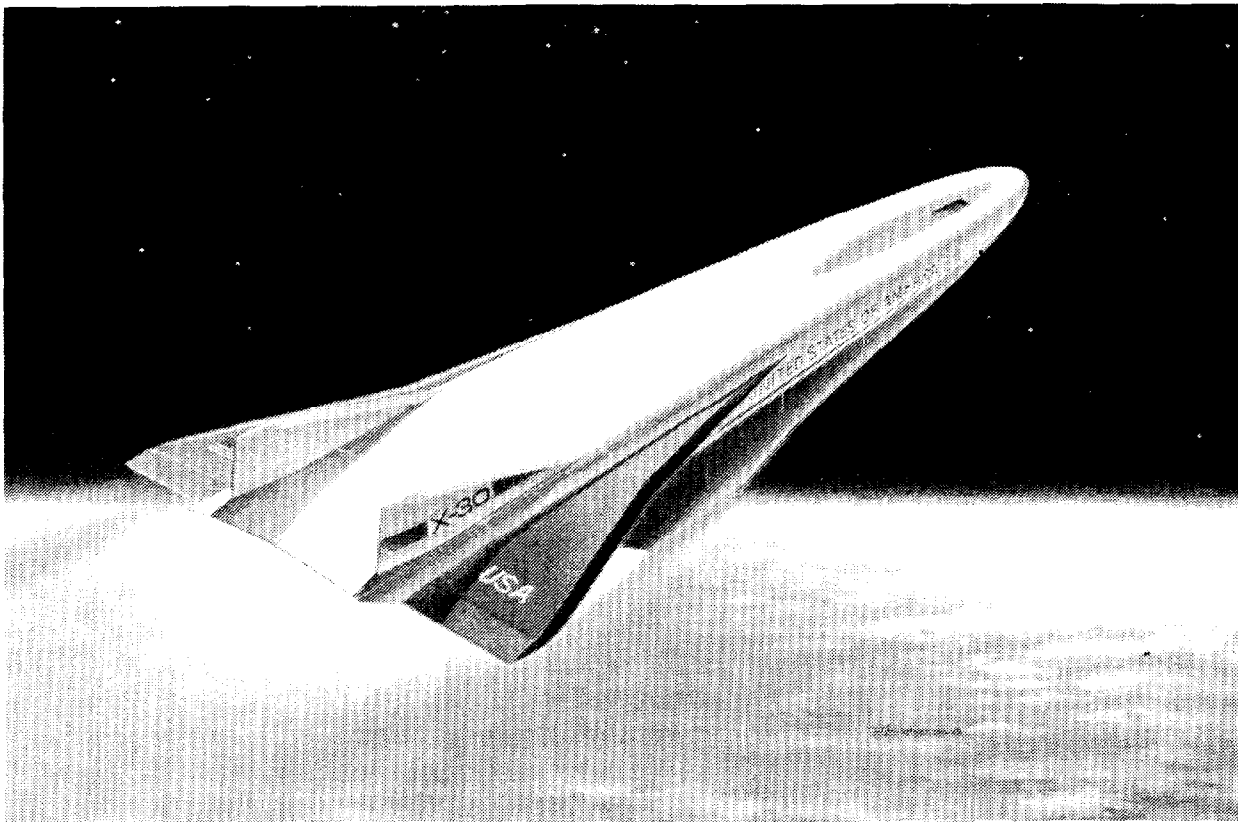
## C. AERONAUTICS

**Finding #39:** The Panel was pleased to note the promulgation on August 12, 1991, of NASA Management Instruction (NMI) 7900.2 on aircraft operations management. This NMI and a companion delineation of aviation safety requirements in the basic safety manual are needed steps in the establishment of a total safety management organization and Agency-wide philosophy of aviation safety for administrative aviation.

**Recommendation #39:** Incorporate aviation safety requirements in the basic safety manual as soon as possible to ensure that NASA personnel have a common reference for administrative aviation safety requirements. Completion of a Headquarters organization to coordinate flight policies throughout NASA is needed.

**Finding #40:** Management of NASA's aeronautical flight research continues to place strong emphasis on flight safety. Procedures for review and approval of the flight programs [from project conception through Flight Readiness Reviews (FRRs)] are adequate to ensure full awareness of the major safety issues involved in each project.

**Recommendation #40:** NASA's aeronautical flight research should continue to be given strong support at appropriate levels to maintain a safe program for preserving the nation's dominance in the aeronautical sciences.



## D. OTHER

**Finding #41:** Crew members working on the Space Shuttle for extended periods have experienced difficulties achieving sufficient sleep. This problem is magnified when two shift operations are conducted. These problems are similar to those experienced by aircraft flight crews in long-haul operations.

**Recommendation #41:** NASA should support a program of research and countermeasure development on crew rest cycles and circadian rhythm shifting to support both Space Shuttle and Space Station operations. This program could be modeled productively after the ongoing NASA aircrew research.

**Finding #42:** Despite acknowledged examples of contributions to aviation safety analyses through human factors research, NASA has not marshalled its resources in this field to study similar problems in spaceflight orbital and ground operations. Efforts in this arena have been stymied by a lack of appreciation of its potential value and the absence of clear guidelines regarding programmatic responsibilities.

**Recommendation #42:** In view of the anticipated increase in manned spaceflight activity during the present decade involving joint Space Shuttle and Space Station activities, NASA's human factors resources should be marshalled and coordinated effectively to address the problems of risk assessment and accident avoidance.

**Finding #43:** NASA has a hierarchy of reporting systems for mishaps and incidents that defines investigation procedures/responsibilities and provides

for developing lessons learned. These reporting systems function quite well for relatively serious accidents, incidents, mishaps, and near-misses. NASA does not have a system analogous to the Federal Aviation Agency's (FAA's) Aviation Safety Reporting System (ASRS) for collecting self-reports of human errors that do not lead to an otherwise reportable event.

**Recommendation #43:** NASA should examine ways to encourage self-reports of human errors and to analyze and learn from data and trends in these reports. Inclusion of coverage of the need for human-error reporting in task team training with an associated method for analyzing the reports could prove to be an excellent method for collecting this information.

**Finding #44:** The Tethered Satellite System (TSS) program was plagued by two quality control problems during the year. One problem was a failure of the bonding between the rotor of the vernier motor and the cork clutch material. The other problem was associated with an error in identifying heat treating requirements for 15-5 stainless steel. Installed components using this steel that was not heat treated should require a waiver before clearance to fly is granted. Failure of 15-5 steel pins in the concentric damper negator motor or tower tabs could potentially impact safety.

**Recommendation #44:** A complete review of the TSS quality assurance program should be conducted before flight in addition to the already initiated

examination of the suitability of the suspect parts.

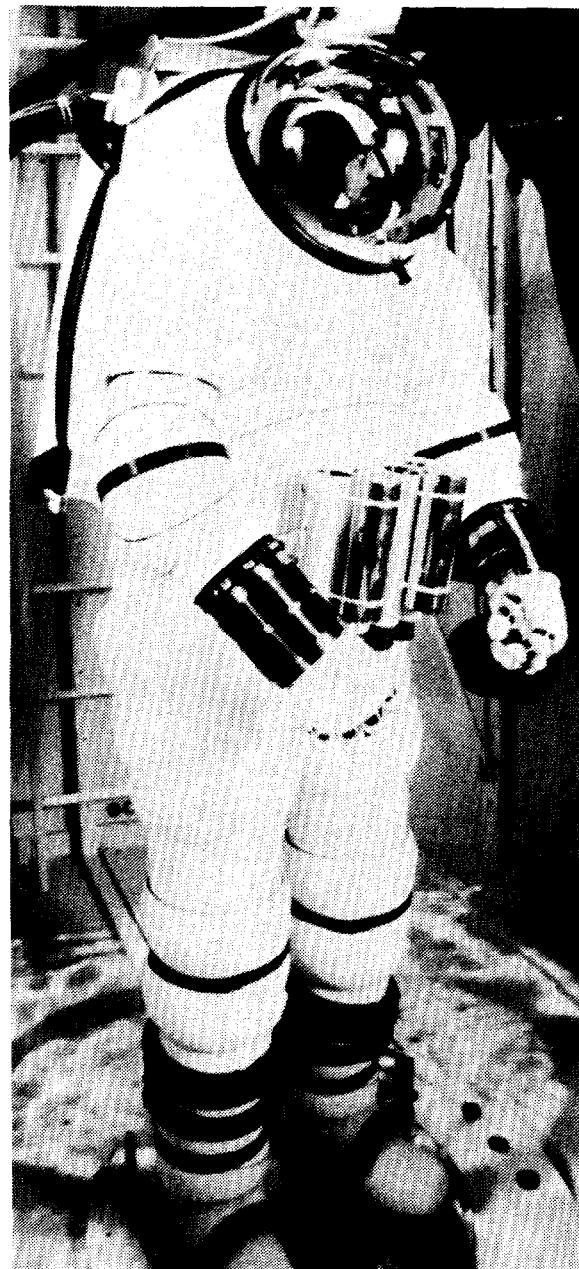
**Finding #45:** Existing plans for Space Shuttle missions such as the Hubble Space Telescope (HST) repair, and the assembly and maintenance of the downsized SSF, highlight potential benefits from the use of an improved spacesuit and extravehicular mobility unit (EMU) to replace the existing suit and portable life support system (PLSS). Limitations inherent in the design of the present system could pose operational for safety problems on these and future missions. The AX-5 and Mark 3 research and development programs have provided an excellent basis for implementing a new, improved design for extravehicular activity (EVA) equipment. Compatibility of the new suit designs with the existing PLSS potentially provides a cost-effective upgrade path.

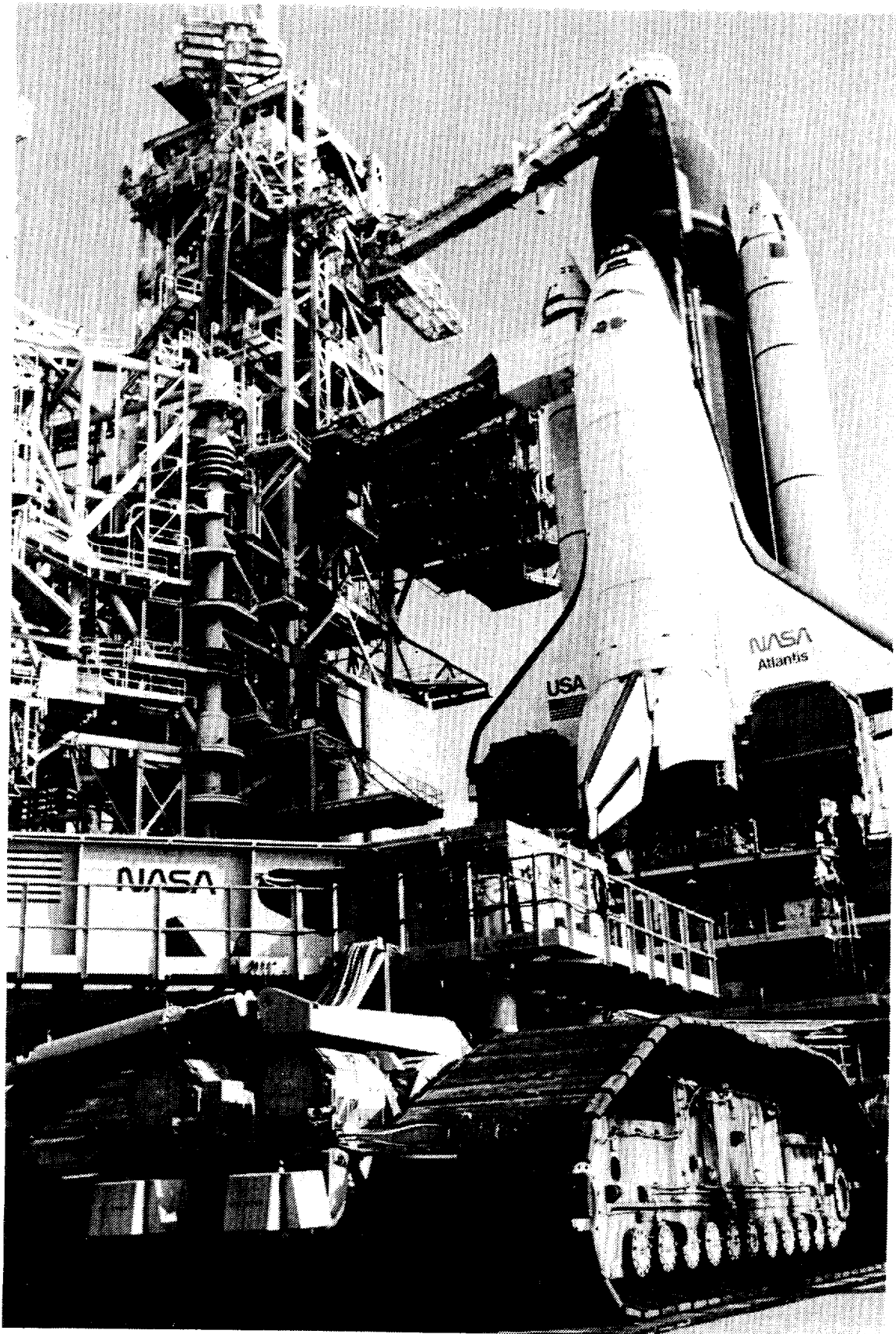
**Recommendation #45:** NASA should reconsider the specification and development of a new suit and EMU based on the information developed in the AX-5 and Mark 3 programs. NASA should acknowledge the need for a new suit and EMU as soon as possible and establish its development and implementation schedule consistent with budget availability. Use of a new suit with the existing PLSS specifically should be examined as an interim safety improvement step.

**Finding #46:** Determinants of the risk of bends during EVA activities have not been fully researched. Existing prebreathing protocols are based on ground-based pressure chamber tests and scuba diving tables. A significant safety uncertainty could be removed if the specific effects of micro-gravity EVA

conditions on nitrogen bubble formation were determined and documented.

**Recommendation #46:** NASA should support the research necessary to characterize more fully the bends risk associated with micro-gravity EVA activities using its extensive expertise at the research centers and the data collection opportunities available during on-ground simulations and Space Shuttle flights.





### **III. INFORMATION IN SUPPORT OF FINDINGS AND RECOMMENDATIONS**

### III

## INFORMATION IN SUPPORT OF FINDINGS AND RECOMMENDATIONS

### A. SPACE STATION FREEDOM PROGRAM

Ref: Findings #1 through #3

Space Station Freedom (SSF) has undergone a major restructuring. Difficult issues in program content and operations have been realistically confronted. Nevertheless, SSF remains a very complex program involving three NASA development Centers, three international partners, a significant ground integration, and launch responsibility for the Kennedy Space Center (KSC) and numerous development and support contractors. Figure 1 depicts the overall program plan and organizational responsibilities. An outline of the administration of program policy and direction is shown in Figure 2.

Geographically dispersed locations and fragmented levels of responsibility have contributed to management complexity, especially in the systems engineering and integration area. Management has attempted to mitigate this situation by combining the systems engineering and systems integration responsibilities into a single office at Reston, Virginia (Level II) and delegating specific implementation authority to the field centers as outlined in Figure 3. The field managers, in administering their responsibilities as Level II staff, have at their disposal the technical and administrative resources of their Centers as well as staff members specifically

assigned to that office. At the same time, they are close to the Level III activity at the Centers where the development responsibility resides. The activity at the Marshall Space Flight Center (MSFC) shown in Figure 4 is an illustration of this arrangement.

The Elements Integration Office Manager at MSFC (Level II) reports programmatically to the Manager, System Engineering and Integration Office (Level II) located in Reston, Virginia, and attends Level II meetings and briefings with managers from other Centers. The manager's relationship with the Space Station Projects Office (SSPO) at MSFC (Level III) remains a typical Level II/III interface. The advantage of the arrangement is in the personnel allocations. The Elements Integration Office Manager has a staff of 13 people supported by Grumman, the Space Station Engineering and Integration Contractor (SSEIC), which has approximately 80 staff members assigned to the MSFC Element Integration Office. In addition, as a consequence of being located at MSFC, the manager also can enlist a full range of specialists from the Science and Engineering Directorate as needed. Similar arrangements exist at other Centers.

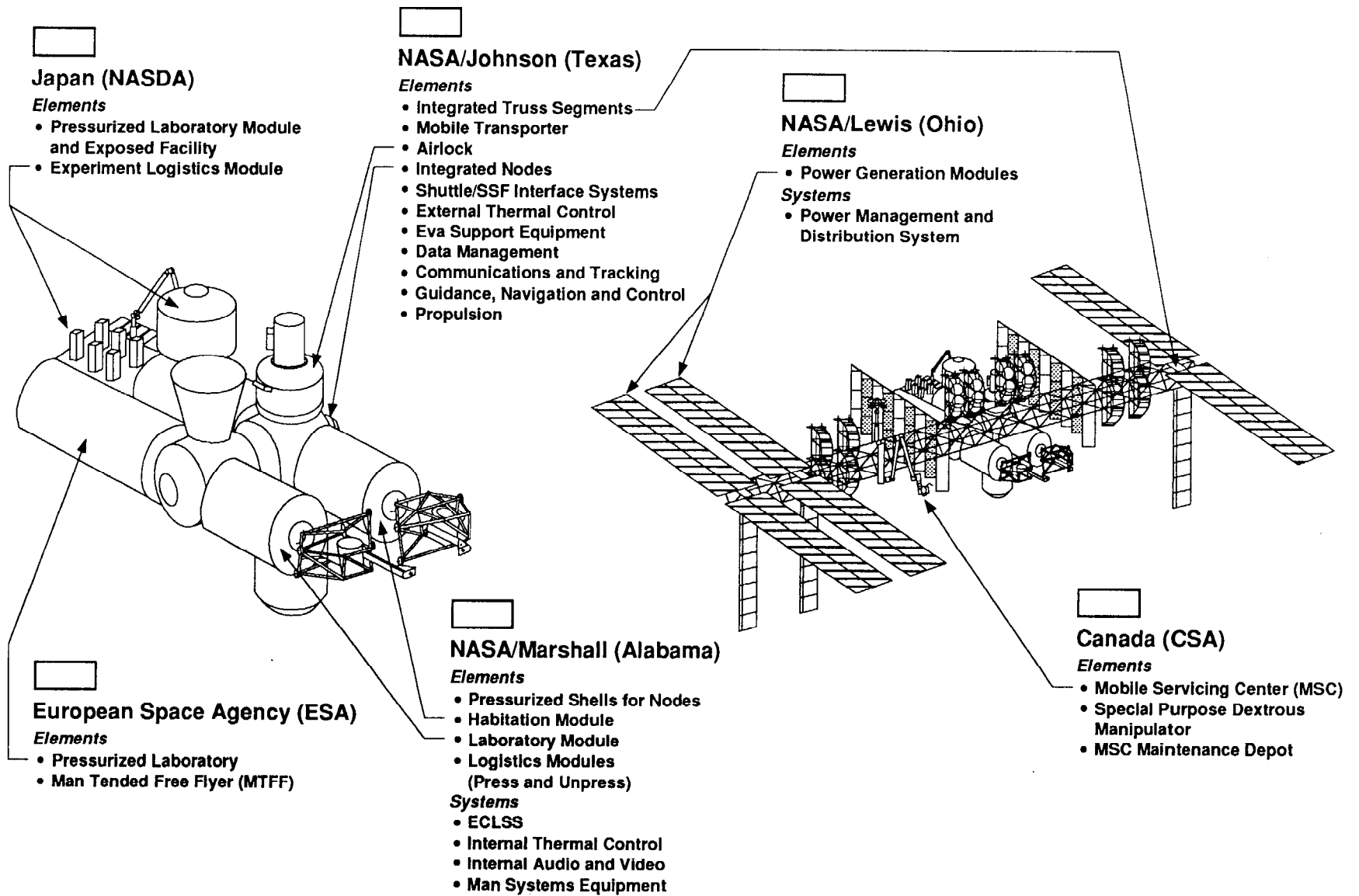


Figure 1. Space Station Freedom Program Plan

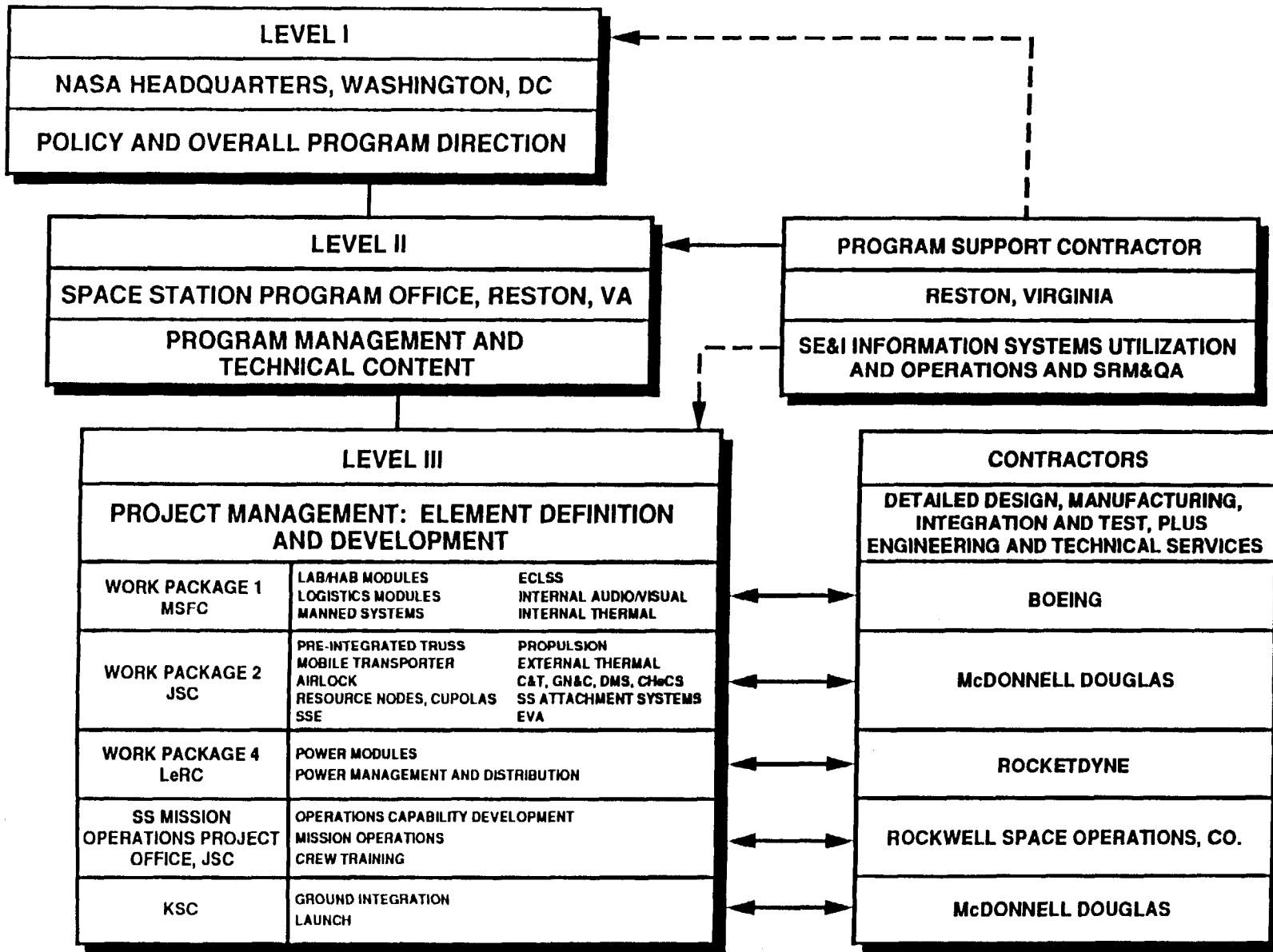


Figure 2. Space Station Freedom Program Organization

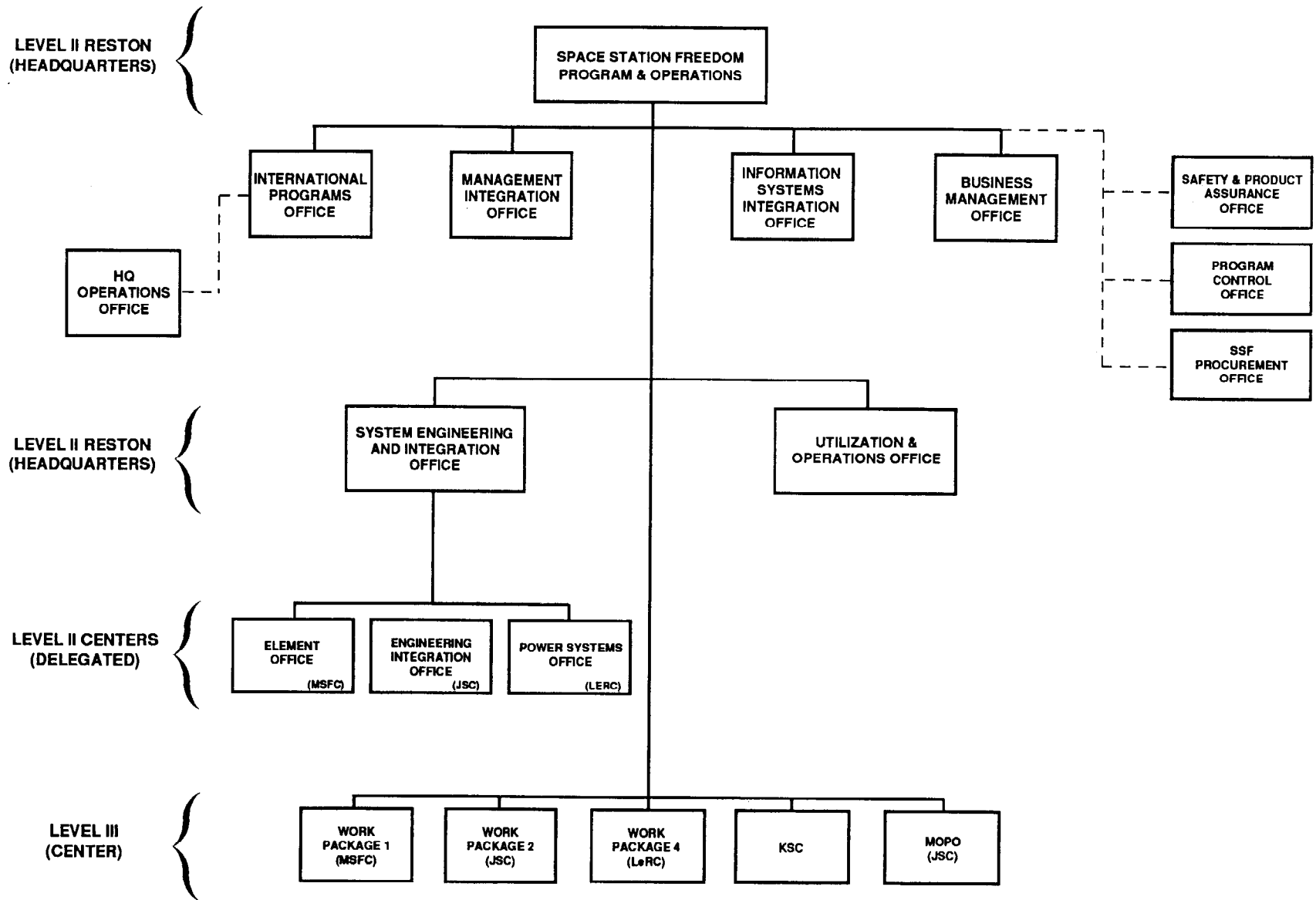
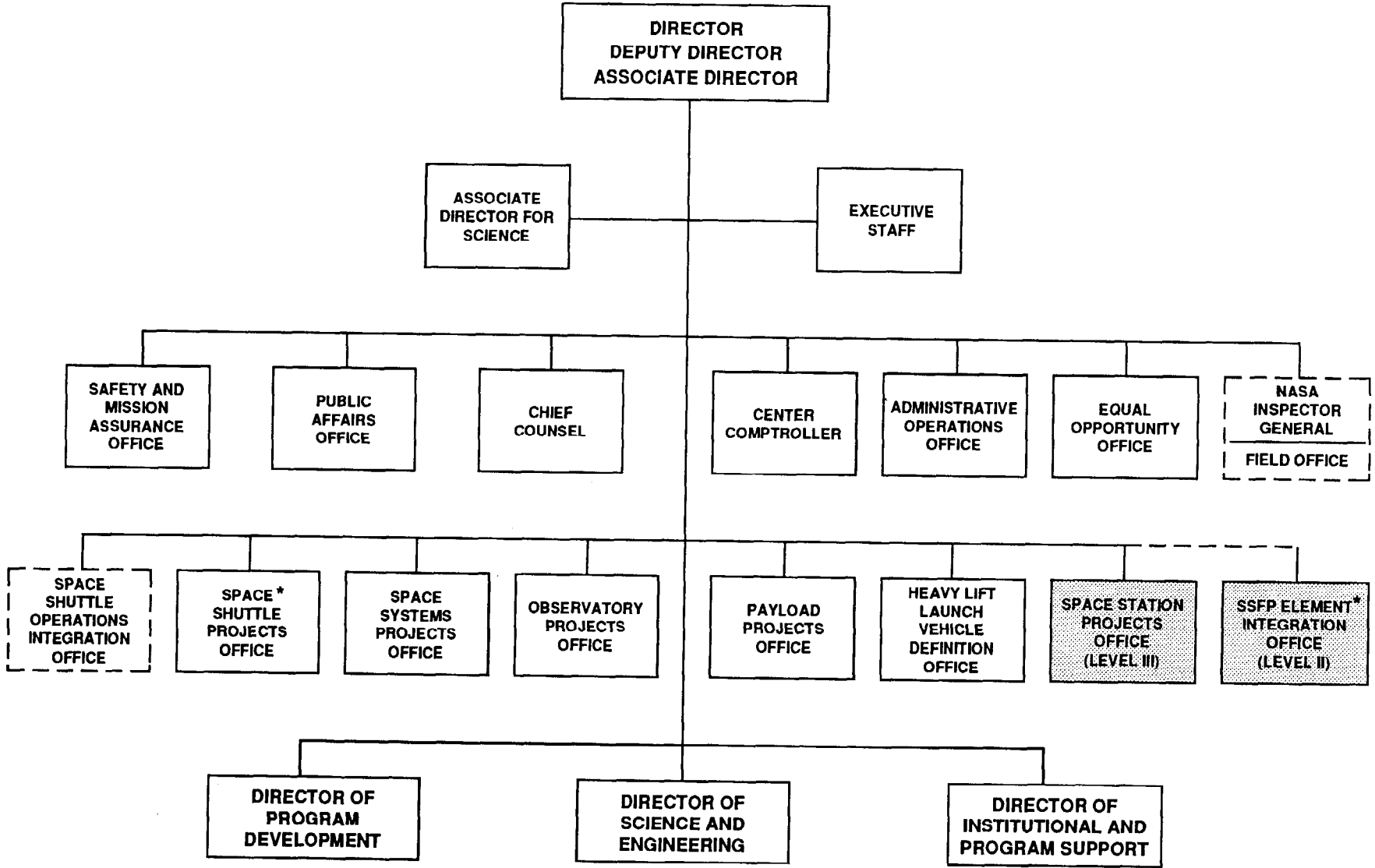


Figure 3. Space Station Freedom Program and Operations





\* MANAGERS ARE LEVEL II EMPLOYEES WHO REPORT TO RESPECTIVE PROGRAM OFFICES, NASA HEADQUARTERS

▒ LEVEL III - II INTERFACE

Figure 4. MSFC Organization

Changes also have been effected in Level II activity at Reston. The new management structure is in place and has established clear responsibility among the various organizations and program levels. Grumman, SSEIC to NASA Level II at Reston, is now undertaking a realistic integration role in addition to the supporting function it has been serving. Communications between NASA and SSEIC have improved greatly. For instance, SSEIC personnel now attend the SSF meetings of key NASA integration managers from which they previously were excluded.

The SSF design changes have had some impacts on safety and risk. For example, use of a preintegrated truss (PIT) structure (see below) greatly should reduce risks associated with the extensive extravehicular activities (EVAs) required by erection of the previous design. On the other hand, the elimination of two nodes reduces the available egress paths and, hence, likely increases risk. Overall, it appears that the program has struck a reasonable balance between reduced cost and complexity and the acceptance of an appropriate level of risk.

Ultimately, the operational risks associated with SSF will depend to a great extent on the availability and type of emergency assured crew return capability. The issue of providing such a capability from SSF continues to challenge NASA. There are several options under study including the development of a dedicated "lifeboat" and utilizing the Space Shuttle. Other factors that may influence selection of a final design include the possible use of an expendable launch vehicle and associated personnel carrier that could be utilized as a return vehicle. Studies

of these various alternatives are only partially complete. Current information appears to be insufficient to select a preferred approach.

**Ref: Finding #4**

The use of truss segments, which are preintegrated with distributed systems and verified on the ground instead of erected on-orbit, has reduced technical risk and made the Space Station a more viable program. The preintegrated truss members (PIT) must be heavier than the original truss elements per running foot because the entire mass of the PIT is subjected to launch loads.

PIT members are aluminum I-beams bolted together instead of the more flexible graphite composite elements that previously were part of the design. The heavier construction allows Orbit Replaceable Units (ORUs) to be located in their optimum positions for accessibility.

Table 1 compares several features of the restructured and original SSF designs.

One benefit of the restructured design is that EVA time has been reduced considerably so that EVA targets are now feasible. This has been accomplished by reducing the demand for EVAs and increasing the efficiency of those that must be performed. Examples of changes that positively impact EVA in addition to the use of the PIT are:

- Providing tools and equipment for independent and/or parallel EVA operations
- Enhancing the utility of EVA support equipment

**TABLE 1**  
**SSF Assembly and Operational Capability**

	<u>Preintegrated</u> (After Jan. 91)	<u>Erectable</u> (Before Jun. 90)
Truss	315 ft.	479 ft.
Sections/Bays	7 Sect.	29 bays
Assembly		
Elements	17	122
Lab/Hab		
Modules	27 ft.	44 ft.
Nodes	2	4
Cupola	1	2
All International		
Elements	Yes	Yes
Assembly		
Flights	16	18
Man-Crews	4	8
KW-Power	56.25	75

- Locating ORUs to simplify EVA operations
- Simplifying the Mobile Transporter.

In the assembly of the PIT sections on-orbit, a capture latch provides final alignment by engaging guide pins after the sections are brought into proximity by the Space Shuttle remote manipulator arm. Motorized bolts then make the final latch-up. There is a chance that these sections may not line up correctly; therefore, damage may occur to the guide pins and bolts when the motorized bolts engage. Because the PIT sections will be assembled on the ground, the opportunity exists to test the alignment and mating procedures prior to flight.

The SSF restructuring has eliminated some risks and hazards inherent in the previous design, but has introduced the following new ones:

- The provision of only one airlock instead of two. Loss of node #2, which contains this airlock, would severely hamper EVA activities.
- A totally "open race track" making it impossible to have dual egress paths.
- The reduction of the atmospheric pressure to 10.2 psia, which increases fire risk due to the increased partial pressure of oxygen.

Although the hazards analyses are proceeding well, many potentially serious items still are contained on the critical item lists. These should be reduced or eliminated as the design process progresses.

**Ref: Finding #5**

The basic architecture and functions of the data management system (DMS) have not changed significantly with the most recent restructuring of the SSF design. Originally, the DMS components exceeded their power allocations. The current DMS design almost meets its weight, power, and volume allocations.

Although the DMS hardware design seems to be proceeding as planned, the software is still a great challenge; it is one of the pacing items of the program. To meet the present delta design review (DDR) schedule, 17 DDRs will have to be accomplished in 1992. This may not be possible unless software development keeps pace.

## B. SPACE SHUTTLE PROGRAM

### **ORBITER**

#### **Ref: Finding #6**

Photoanalysis of the STS-28 (OV-102, Columbia) flight showed larger body flap deflections than were calculated. The flaps are in a turbulent flow field, which creates a hinge moment spectrum greater than that used in the structural fatigue analysis. The loads are all within the structural limits, but the fatigue analysis shows a reduction of allowable flights from 100 to 77.

After the higher hinge moments were observed, additional ground tests were conducted using recalibrated strain gages on the body flap actuator as well as additional instrumentation on the rotors and stators. Three types of loads were applied. It was discovered that an additional load path existed back through the driving gear to the supporting structure. The original equations assumed only four load paths at the actuators. With a fifth load path, it is necessary to develop a new set of equations. It also was discovered that the actuators were more flexible than originally assumed and that the OV-102 (Columbia) actuators were more flexible than those on OV-103 (Discovery) and OV-104 (Atlantis). This is attributable to increased tooth width on the OV-103 and OV-104 actuators. Additional tests are planned to further evaluate the body flap structure.

#### **Ref: Finding #7**

To apply traditional inspection techniques, such as visual and X-ray methods, disassembly frequently is required. Therefore, a Shuttle Modal Inspection System (SMIS) has been developed to augment more conventional structural inspection techniques. Although not a replacement for conventional inspection processes, SMIS is capable of finding some defects without the need to disassemble the system being tested.

SMIS uses changes in structural dynamics characteristics to detect problems such as wear of actuators, honeycomb debond and cracks in primary structure that are large enough to change stiffness. Actual modal tests experienced on OV-102 and OV-103 have proven the benefits of this system to detect structural damage. To apply SMIS, each Orbiter part must be tested to establish baseline modal information to serve as a standard to determine if structural changes have occurred.

Currently, it is planned to use SMIS on a regular basis for data acquisition and analysis of Orbiter body flaps after every fifth flight.

**Ref: Finding #8**

In the past, tile bonding process controls and bond verification testing were used to ensure the integrity of the thermal protection system and identify substandard bonds. Approximately 20,000 to 27,000 tiles were tested on each individual vehicle. Typically, only 13 to 64 tile bond failures were found. Initial checkout of OV-105 (Endeavour) has shown only 13 failures.

Use of such bond verification testing has been discontinued because it was determined that tactile and visual inspection techniques by specially trained and experienced inspectors provided adequate results. These "Wiggly" tests depend on the sensitivity of the inspector's touch to determine if tiles are loose. The inspectors also examine and measure step and gap dimensions. Such tile inspections are conducted before each flight.

Tile inspection clearly is dependent on the availability of skilled inspectors. New quantitative methods could be devised to reduce the dependency on qualitative human inspections. These likely will take some time to develop. Therefore, new inspectors must be trained well in advance of their need to support the Orbiter flow.

**Ref: Finding #9**

The Space Shuttle Program has commenced its first major Orbiter overhaul cycle with work on OV-102 (Columbia) at the Rockwell Palmdale facility. Future overhauls and major modifications on the other Orbiters presently are scheduled to take place at KSC. With aircraft systems, line maintenance and overhaul or major

modification functions are typically organizationally separated even when they are conducted at the same location. This has worked well with aircraft and is likely a good model for the Space Shuttle Program to follow. Simply, different types of planning, management skills, and experience are required by routine turnaround flow and the more major overhaul and modification operations.

**Ref: Finding #10**

The Space Shuttle system presently includes an autoland system that provides automated guidance capable of navigating the Orbiter to the selected landing runway. Automated approach guidance requires the availability of a well-calibrated microwave scanning beam landing system. Completion of a successful landing requires the crew to manually deploy the air data probes and landing gear by activating cockpit switches. This is similar to the situation with commercial aircraft. The crew also must be active in the post-touchdown rollout phase to ensure a safe transition to wheel stop because no automatic braking is provided. The present system is viewed by the Space Shuttle Program as an emergency backup to the commander and pilot, but there are no documented decision rules for its use or operational scenarios under which it is mandated. It has not been tested all the way to touchdown during an actual flight. However, a detailed test objective (DTO) is being developed by the Space Shuttle Program to provide for at least one full automatic landing.

The increased duration of Space Shuttle flights as part of the Extended Duration Orbiter Program (EDO) has raised the issue of the need to qualify the existing

system during actual flights. It also raises the issue of the possible need to fully automate all landing, rollout, and braking functions so that the Orbiter could be returned safely from orbit without any crew intervention, if necessary.

Before discussing the need for possible enhancements to the present capability, the status of the present subsystem must be reviewed. The existing subsystem is designed to provide guidance information to the Orbiter through all of the descent flight phases:

- Entry guidance (500,000 feet to Mach 2.5)
- Terminal Area Energy Management (TAEM) (Mach 2.5 to 10,000 feet)
- Approach and landing (10,000 feet to touchdown).

Although the crew must deploy the air data probes and landing gear, there is an automatic speed brake deployment and positioning that occurs independent of the guidance system. This is similar to the prevailing autoland systems in commercial airliners.

The Space Shuttle system differs from those in airliners because it defaults to automatic mode when deorbit commences, and remains there unless the crew switches to the control stick steering (CSS) mode (manual flying). The switch to CSS can be accomplished through a pushbutton on the instrument panel or, on an axis-by-axis basis, by moving the control stick. This is known as "Hot Stick" downmoding to CSS.

The TAEM phase is of particular interest because it determines the energy state and runway alignment of the vehicle at a time in the descent when correction for low or high energy states is possible. TAEM usually is flown manually by the crew, although guidance can adequately control the vehicle around the heading alignment cone and on to touchdown. When the crew flies manually, they tend to manage energy somewhat less aggressively than would the programming of the present automatic system. This increases crew comfort and reduces loads on the Orbiter. Effort presently is being devoted to examining a change in the guidance system to emulate more closely the trajectories actually flown by the crews.

The existing automated approach guidance system never has been fully flight tested. The second Space Shuttle flight, STS-2, left the auto mode engaged until the latter part of the TAEM region and demonstrated that the system was capable of returning the vehicle to a flyable energy state from a low energy state. STS-3 left the system in auto until the commander's scheduled takeover at 125 feet. The system was on energy and trajectory at takeover, but the pilot had difficulty getting "into the loop," and an uncomfortable situation developed. The final several thousand feet of a Shuttle's descent involves relatively complex flare maneuvers with which a pilot might be expected to have difficulty when retaking command.

A DTO for remaining totally in the automatic mode to touchdown was scheduled for STS-16 (41F). However,

when STS-15 (41D) had an engine-out pad abort, flights were remanifested and the DTO was canceled and never rescheduled. As a result, although there have been numerous simulation runs, computer modeling, and post-flight analyses of guidance commands, there never has been a flight demonstration of the auto guidance capability all the way to touchdown. Therefore, the cognizant contractor would not certify the system because of the absence of a flight test.

Rockwell is undertaking a reverification of automatic entry and autoland as part of their funding for the EDO missions. However, this does not mean that it has been determined that autoland will be needed for EDO or that a decision to use it has been made. Plans are being formulated for an autoland DTO to be executed within the next year. This will begin the process of in-flight verification of the system. Future analyses are planned to determine if additional flight tests will be required to develop an operationally certified system.

The existing automatic approach guidance capability represents a sufficient foundation of hardware and software to support the contemplated DTO. Eventually, a fully certified system may require certain enhancements such as increased redundancy, decision rules for leaving the automatic mode engaged, and automated gear and air data probe deployment.

There are four basic situations under which Space Shuttle flight safety would be enhanced by the use of some degree of automated landing assistance. These are:

- *Crew unavailability.* This is a situation in which the crew cannot perform their piloting functions adequately because of external conditions. For example, a situation of unavailability might occur if the windscreen of the Orbiter became completely obscured or the cockpit filled with smoke or fumes making it impossible for the crew to guide the craft visually.
- *Obvious crew incapacitation.* The crew may become physically or mentally incapacitated in a manner that allows them or ground controllers to detect the incapacitation. Such obvious incapacitation might range from total loss of consciousness to loss of visual accommodation or the ability to move.
- *Subtle crew incapacitation.* The crew may become physically or mentally incapable of flying the Orbiter in such a manner that both they and the ground controllers continue to believe that they, in fact, are in control. Subtle incapacitations have been experienced in many high stress environments. They typically involve phenomena in which the human sensory and/or cognitive mechanisms are misleading. Examples might involve impaired depth perception, spatial orientation, or eye-hand coordination.
- *Capability Limitations.* There are flight situations, particularly abort maneuvers, that stress crew

capabilities to the limits. This stress may be particularly acute if a landing is required into a relatively unfamiliar field.

For situations involving capability limitations, computer assistance through an autoland system can augment or replace the human crew. This has the added benefit of permitting the crew to undertake other critical tasks besides the landing guidance and management of the Orbiter. The generally quicker response time of a computerized system as well as its ability to store and recall vast quantities of contingency information make a standby autoland system a valuable resource.

In the event of crew unavailability or incapacitation, the crew may retain some limited functional capability. For example, they may be able to activate switches to deploy air data probes and landing gear. Under these circumstances, an automatic landing system that required minimal crew interventions, such as switch activations, likely would represent adequate support. Alternatively, the crew may be totally incapable of participating in the landing operation due to unconsciousness or the inability to move or function. In this case, a fully autonomous autoland capability would be required to ensure the safe return of the Space Shuttle. This system might need the capability of remote activation to account for situations in which the crew becomes totally incapacitated after downmoding to manual (CSS) steering.

The situation of subtle incapacitation raises additional salient issues. If the crew is unaware that their performance is degraded, it is illogical to expect them to decide to execute an automated approach. This suggests the need for

objectively defined operational rules for the use of automated guidance. For example, a rule might require the use of autoland for all missions exceeding a specified length (e.g., 10 days). The system also should include specific decision rules for engaging the automatic mode (or leaving it engaged) during flights not covered by the operational rules. It also would be beneficial to research possible crew performance measures that could be used during flight to assess the need for an automatic landing. Such measures could be examined during actual Space Shuttle landings by collecting data from secondary tasks performed by nonflying members of the crew.

The reluctance of the crews to give up their manual landing opportunities as well as their concern about the "takeover" problems based on the STS-3 experience is understandable. However, it would seem that a takeover at such a low altitude would be highly unusual and might not be sufficiently credible to include in the certification criteria.

The basic flight controls and computers are in use and have been shown to be reliable during Space Shuttle missions. However, additional sensors and inputs may have to be employed for a full feature and safe "nonpilot participating" autoland. This may call for a safety review of the extended system.

With commercial airplanes, the overall safety level of the total system, airborne and ground, is checked carefully by a comprehensive failure mode and effect analysis (FMEA) to ensure that the whole system will meet a prescribed safety level. This analysis is conducted independent of any consideration of pilot intervention. A significant factor



of the FMEA in commercial aircraft probability analysis is the evaluation of fault-free performance. That is, out-of-tolerance performance not due to a detectable fault that could lead to an incident, possibly an accident, must be considered when arriving at the overall predicted safety level.

In commercial aircraft, autopilots used for approach/landing are designed to have various redundancy levels depending upon their operational use. A fail passive or fail-benign system is used for operation down to 100 feet. If a fault occurs, the autopilot will automatically disconnect and warn the pilot, but not disturb the flight path. Airplanes conducting such landings in low visibility using fail passive systems generally are certified for use in approaches to low altitude (e.g., 100 feet or so). This is provided it can be shown that the pilot can take over and conduct a landing or go-around safely. If the automatic pilot is to be used down to touchdown without pilot intervention, such as a go-around or path correction, a fail operational system of some form is required and a very low probability of a failure that could lead to a loss of control must be established before the system can be certified. The probability of a safe go-around can mitigate this value somewhat. Obviously, this is not the case with the Space Shuttle.

Without considering pilot intervention, the Space Shuttle system will need to land with an extremely high probability of being within prescribed parameters of touchdown vertical velocity limits, lateral and longitudinal dispersions, and any other limits peculiar to the Space Shuttle such as body angle. The

confirmation of the possibility of a malfunction or fault-free performance outside limits would need to be shown to be extremely improbable. Therefore, a Space Shuttle autoland system would need to provide full fail-operational performance through touchdown and rollout.

Another vital aspect of autoland certification is to ensure that the landing parameters, flare profile, decrab maneuver, transition to rollout, etc., conform to what a reasonable pilot would tolerate. In the early days of commercial autolandings, these profiles were determined by software engineers. Although they achieved the accuracies required, they were unnatural and unacceptable to the pilots, thus causing a potential and possibly dangerous pilot intervention to occur.

Today, the flight profiles flown by commercial autoland systems have been refined to be so natural and consistent that most airline pilots say "the system does a better job than I do." If NASA embarks upon a program to develop natural landing maneuvers by the automatics that are pilot acceptable, it also will have the distinct advantage that pilots will be more likely to use the system, even when it is not mandated. Thus, this will provide valuable operational experience and data and, in the end, a higher safety level.

On the assumption that operation solely by the human pilot as the prime safety element may not be viable under certain operational circumstances, a fully automatic landing system becomes essential to the safe completion of a Space Shuttle mission.

**Ref: Findings #11 through #13**

During the year, NASA continued its independent review of the verification and validation process related to Space Shuttle software. This independent review has demonstrated its value by finding failure modes that previously were unknown. Increased involvement of the Office of Safety and Mission Quality with software safety also was a positive step.

Software verification and validation can take several forms including:

- Continual oversight and review of the process
- Oversight and review of the generation of the tests used in the process
- Complete verification and validation conducted by a totally independent organization.

Costs and benefits of these approaches vary considerably. The cost of an ongoing, independent review of the verification and validation process and of the test generation is relatively small compared to the total cost of the process. The present ongoing, independent review has demonstrated the value of this activity and should be continued. Although an internal steering committee on embedded verification and validation has been formed, it was not until the independent contractor became involved that a "roadmap" of the process and generation of the tests used was established. The internal steering committee has not succeeded in carrying out the necessary functions on its own.

Now that a complete roadmap for the verification and validation process is available, the Panel believes that the independent contractor should review the process, end to end, and look for ways to simplify it. At present, it involves a great number of machines and people. In addition, the independent contractor should investigate the process by which the tests for the verification and validation process are generated. It is essential that the independent contractor utilize personnel intimately familiar with NASA's software processes. An independent contractor not utilizing such personnel would have great difficulty in adequately carrying out this function.

Independent performance of the tests, however, is another matter. Costs associated with the verification and validation process are very high. One unofficial estimate puts the cost as high as \$500,000 for the physical apparatus alone. Further, the process can only be reliably performed by personnel intimately familiar with the software production process. Therefore, great care must be taken in any proposed decision to independently perform the verification and validation function. There must be both an acceptance of the substantial costs involved and a plan to acquire the experienced personnel necessary to carry out the work. ASAP believes that these two factors mitigate against the third listed alternative, independent performance of the verification and validation tests. Simply, the potential gain does not justify the cost.

The new general purpose computer (GPC) hardware seems to be performing well. The single event upsets (SEUs) were no more numerous than expected. Indeed, accuracy of the predictions based upon NASA's model of SEUs was impressive. A cursory analysis concurs with NASA's estimate that the probability of an SEU-induced failure is negligibly small.

There is still a potential problem arising from the eventual saturation of usable memory on the new GPC. While the time horizon of the "new" GPC has been extended somewhat by moving some requested upgrades into procedures and slowing the software change process, the conclusion is the same. Long before the end of its planned lifetime, the "new" GPC will be saturated and a further change will be necessary. It is still the case that any foreseen possibility of further upgrade will require massive reverification and revalidation. With the extension of the time at which this impasse will occur, NASA has the time, if it acts promptly, to plan carefully for this next change and complete it at minimum cost and turmoil. A small planning effort on the next generation computer upgrade should be started as soon as possible. This study should not be constrained to living with the current architecture, and should involve others in NASA who have been studying long-term computer evolution for space applications.

The movement of some requests for software upgrades to crew procedures is a matter of serious concern. The crew already has a very large number of procedures with which to be familiar. Adding to that load, particularly with items that could be handled easily with greater reliability and safety by software,

does not seem wise. Procedures such as "do not touch the keyboard for X seconds after the occurrence of event Y" can be handled easily by software. If such procedures are contingencies that are employed infrequently, the chance of error when they are needed rises.

A review of all computer-related procedures to ascertain whether or not there is significant potential for design-induced human errors should be mounted. This review should include crew representatives, experts on human factors, and members of the Safety and Mission Quality organization.

#### **SPACE SHUTTLE MAIN ENGINES (SSME)**

##### **Ref: Findings #14 through #17**

The in-flight performance of the Space Shuttle Main Engines (SSMEs) has been very consistent and without significant anomalies since the return-to-flight after Challenger. There are now sufficient engines at KSC to provide four shipsets for the Orbiters plus three spare engines. The practice of removing all three engines from the Orbiter after each flight and conducting the post- and pre-flight tests in the "engine room" has proved beneficial and effective. Except for the high-pressure turbopumps, the major components of the engines have demonstrated service lifetimes in excess of the specified 55 equivalent Space Shuttle flights.

The Phase II component improvement program designed to enhance the safety and/or reliability of the current engine components has continued to make progress. The status of the changes to the major components is:

- High-Pressure Fuel Turbopump (HPFTP): All changes to this turbopump have completed the certification requirements; flight units are being built. The machine has demonstrated the requisite 10,000 second run time (20 flights) and was to have been authorized a service life of a "green run" on the test stand plus nine flights (half certification life). The failure of a high-time HPFTP turbine blade in test engine 0215, most probably the result of a blade material flaw, has resulted in a reduced "certified operating time" of 7,000 seconds (14 flights). This is the equivalent of a service life of a "green run" plus six flights. A new Computer Tomography blade material inspection technique has been implemented, which will allow the restoration of the 10,000 seconds certification. Pumps with such blades are being assembled, and flight use is estimated for the middle of 1992.
- High-Pressure Oxygen Turbopump (HPOTP): As noted in last year's report, the SSME project decided to abandon its attempt to certify the HPOTP for 10,000 seconds of service life and instead opted to certify the turbopump so that the pump-end bearings can be used for three flights and the turbine-end bearings used for six flights before replacement. To accomplish this, changes to the inducer/inlet, bearing cage coating, ion implantation of the bearing balls, and a material change to the jet ring to increase its fatigue-life were incorporated and certified. Improved on-engine inspection tools for the turbine-end bearing

have been developed and are in service. In-flight strain-gage measurements of the vibration signature of the pump-end bearings to detect early signs of bearing wear are also a part of this configuration. Experience to date with these measurements has been satisfactory. A number of HPOTPs have been flown three times.

- Single-tube Heat Exchanger: The fabrication process for producing the 41-foot long single tube for the heat exchanger has been developed and 10 tubes have been completed. Two tubes have been coiled, and mockups and test specimens are being built. This represents a major hurdle in this program. One coil is in the process of being welded into a powerhead and is to be tested in mid-1992. Certification is scheduled for completion in FY 1993.
- Phase II+ Powerhead: The Phase II+ Powerhead (also known as the two-duct powerhead) was tested last year. As noted in last year's report, both injector erosion and chamber wall blanching were experienced. On the positive side, lateral pressure gradients and velocity profile nonuniformities were reduced substantially. Since then, the flow shields on the injector posts were modified, and tests on a second powerhead were conducted. Injector erosion was eliminated, but main combustion chamber (MCC) blanching and wall damage still were experienced. This has been attributed to a high flow resistance coolant circuit in the specific chamber used. Two

units have been built to continue development; one with the current design combustion chamber and one with the large throat combustion chamber. Tests have been conducted with the large throat main combustion chamber (LTMCC) unit with very satisfactory results (the absence of blanching in these tests is the result of improved cooling design in the chamber).

As noted in last year's report, the LTMCC was tested on engine 0208. In some 3,700 seconds of testing, including 26 starts, the predicted benefits were verified. In addition to reductions in the chamber pressure, turbine temperatures, and speeds, the hot gas wall temperature in the chamber was reduced about 100°F. This will have a significant effect on the rate of combustion chamber blanching and cracking. Analysis indicates that using the LTMCC would increase the margin-of-safety of selected engine components by 12 to 30 percent. The testing noted above with the Phase II+ Powerhead has increased the accumulated run time of the LTMCC to 5,000 seconds. Unfortunately, the LTMCC development was tied to the Advanced Fabrication Project whose results were to be incorporated no earlier than mid-1997. Were this not the case, the benefits of the LTMCC could have been realized much sooner, as the LTMCC does not depend on improved fabrication processes to achieve increased margins. Because of NASA budget constraints, funding for both of these efforts was eliminated for FY 1992. To the detriment of the program, all activity on these efforts will come to a halt before mid-1992.

The design verification system (DVS) testing (both laboratory and rig tests) of the components of the Pratt and Whitney (P&W) Alternate Turbopump Program (ATP) is substantially complete including demonstrations of component life. Some data still are being analyzed, but results to date look good. Significantly, the bearing materials and coatings have been selected and proven. An acoustic emission probe installed for the bearing rig tests shows promise of serving as an in-flight health monitoring instrument. Spin tests of shafts, disks, and impellers have verified the burst margins of these parts. Note that these test specimens were heavily strain-gaged so that data could be obtained to verify the structural analysis models of these critical components. A few DVS tests await the build of final configurations.

- HPFTP: Testing of the HPFTP on the P&W E-8 test stand and of unit 4 on an engine at Stennis Space Center (SSC) revealed a number of problems with the design. Among them were thermal cracks in the first turbine vane inner shroud, tip seal displacement on the third pump impeller, main pump discharge housing vane cracking, and turbine inlet housing strut and slot cracking. Fixes for these have been devised and are in work. Some have been incorporated into unit 5, which has been run at SSC for reasonably long times at 100-percent rated power level (RPL) and has reached 109-percent for a brief time. The plan is to have all fixes incorporated by unit 7.
- HPOTP: This turbopump encountered more difficulties than its fuel counterpart during

development testing. Among them is a synchronous vibration problem at high power levels when pumping LO<sub>2</sub>. Many changes to the mechanical design and assembly details have been incorporated in an attempt to solve the rotordynamic problem. This includes increasing the tiebolt load, the pump-end ball bearing deadband, and the damper seal diameter. So far, the changes that have been incorporated have performed well during the E-8 test of unit 05-1, which ran to 104-percent RPL with acceptable vibration characteristics. This unit has been cleared for 100-percent RPL operation on an engine. Heavily instrumented unit 4-1D was used to verify some additional improvements. It ran satisfactorily to 111-percent RPL with LO<sub>2</sub> on E-8. Unfortunately, unit 6 (which incorporated a de-swirler, in addition to other changes) exhibited rotordynamic instability at 109-percent RPL. It is believed that the cause of this phenomenon has been identified. Follow-on units will include additional changes to attempt to eliminate this cause.

Integrated Tests: The tests of the HPFTP on an engine with the current HPOTP have shown that the transient characteristics of this machine generally are compatible with the rest of the engine system during start and shutdown. There are differences, of course, because of different moment of inertia and breakaway torque of the new machine. As a result, some valve sequencing had to be modified to reduce the fuel preburner ignition

temperature spike. Some additional tuning will undoubtedly be required. Performance of the HPFTP, as measured on the engine, agrees well with the data obtained in the E-8 tests. Testing of both the P&W HPFTP and HPOTP on an engine is scheduled.

In summary, as in most turbopump development programs, the problems encountered in the ATP lie in the (subtle) mechanical details of the design. Problem causes include details such as clearances, seals, venting of volumes enclosed by cover plates, effects of damping seals and bearing preloads on rotordynamics, and effects of thermal transients during startup. The ability to determine the causes of the problems encountered has been enhanced greatly by the use of component test rigs and, perhaps more importantly, availability of the E-8 turbopump test stand. Coupled with good and extensive instrumentation of the development units, these facilities allow rapid identification of problems and permit rational corrective action.

Operation of the E-8 stand has improved much since last year. It is reported that two out of three test attempts now lead to successful runs - excellent performance for so complex a facility.

Engine-level tests have revealed some system issues but, so far, nothing of major consequence. Schedules are still optimistic. Significant progress has been achieved since last year. Engine tests with both turbopumps installed will be a major milestone in the near future.

In a recent decision resulting from budgetary problems, NASA has decided to cancel work on the P&W HPFTP and

to continue only the development of the P&W HPOTP. The plan is to use this new HPOTP in conjunction with the current HPFTP. While such an engine configuration is feasible, it will not achieve the operating margin increases sought for the engine system. NASA has made provisions in its planning to review the status of the P&W HPOTP development in 1994 and reconsider the cessation of HPFTP development at that time.

#### **ADDITIONAL ORBITER COMPONENTS**

**APU Turbine Wheel Blade Cracks:** Blade root and tip cracks have existed since the start of the program. The turbine wheel speed is 72,000 rpm, with a high speed of 81,000 rpm. A design revision was initiated in December 1987; it produced 15 wheels that have accumulated 210 hours with no cracks. By the time this report is published, all APUs will have been equipped with the new turbine wheels. The new design wheels are certified for 20 hours with a 75-hour certification test to be completed in the first quarter of 1992.

**APU Gas Generator Valve Module Seat:** The shutoff outlet seat has evidenced cracks. The investigation of the launch scrub of STS-31 showed that the seat was broken and a piece missing. The consequences could be a reduced APU output or possibly a shutdown. As a result, a liquid leak check of the valve prior to flight is required as well as a valve replacement every 18 months.

**Orbiter Drag Chute:** The plan is to use the chute on every landing because it enhances directional stability. Structural requirements were validated by analysis. The drag chute system was tested

successfully at the component and system level. There still are a few tests remaining. All nominal condition tests with the B-52 have been completed. Tests to expand the envelope still have to be conducted.

#### **SOLID ROCKET MOTORS**

**Ref: Findings #18 through #21**

Work performed on the Advanced Solid Rocket Motor (ASRM) to date generally has been well-conceived and of high quality. The schedule does not have much contingency time. Although techniques can be made to work adequately, it might take considerably longer than planned because there is a lot to integrate.

There are concerns about scale-up of the pilot propellant mix and casting facility. Many parameters and processes have not been fully determined. However, Aerojet has produced a substantial amount of similar solid propellant using continuous production processes so the basic techniques are familiar. The continuous solid propellant production facilities involve a variety of mixing and transport facilities. Safety concerns arising from propellant remaining in the transfer lines have been addressed. The propellant requires a period of 40 to 50 hours to gel, and can be expelled from the transfer lines for a significant time after it enters. Hazard analyses revealed no credible hazard that could prevent evacuating the lines for as long as 15 hours. The propellant is normally in the transfer tube for only about 30 minutes.

Safety devices are installed on the propellant flow line to limit the spread of fire in case of an accident. The flow

line transporting the uncured propellant has several fire breaks to prevent propagation of a fire along the tube. The basic safety device is an explosive-fired guillotine valve that interrupts the flow, with a water spray on the propellant to lower the temperature below the ignition point. In addition, there is a collar in the flow line upstream of the guillotine and on the casting pit side of a fire wall that can be blown to allow the propellant to flow out on the floor and prevent pressure buildup. A matter that must be considered is cleanup after an accident involving a dump of uncured propellant on the floor. The continuous mix pilot plant at Aerojet provides a way of proving a new propellant and upgrading the equipment before establishing a full-scale facility at Yellow Creek. The major differences between the pilot plant and the full-scale facility are equipment size and process control software. The pilot plant production rate is 1,000 to 1,400 pounds/hour with the full-scale facility producing 20,000 to 26,000 pounds/hour. The ultimate particle size of the propellant is dependent on parameters such as geometry of piping, length of lines, and fluid working pressures that may not be directly scaleable. There are many challenges such as metering of propellant solids, pre-mix of iron oxide and aluminum, and real-time process control. Upscaling the rotofeed deaerator and pump equipment probably presents the greatest challenge.

The propellant manufacturing process includes several methods to ensure the quality of the product. There is a 30-minute delay loop in the propellant lines that permits extracting and analyzing a sample before the material reaches the casting pit. In addition, small test

articles are cast with each batch. Propellant samples are tested after casting to ensure burning properties are to specification.

A new method for assessing propellant quality is under development. This Fourier Transform Infrared/Factor Analysis (FTIR/FA) produces "fingerprints" of the propellant being produced. If the development proves successful, it could be used on-line to eliminate most of the laboratory testing during production.

Obviously, successful development of the insulation strip winding process will be a marked improvement in cost and time to the present hand lay-up method used in the Redesigned Solid Rocket Motor (RSRM) installation. The extruder equipment that produces the insulation material in the process development is identical to that specified for the Yellow Creek facility. Initial tests of the stripwinding were conducted on bare metal that had been neither cleaned nor treated with adhesive. These tests were successful in that the insulation did stick to the inside of the casing.

It is necessary to develop a data base for strip winding before producing the 48-inch insulation test articles. A 48-inch long section of a 150-inch diameter case will be developed for the field joint test article. However, the boom travel will have to reach 400 inches for the full-scale motor. Finally, the entire process will be verified in the development and qualification motor tests.

The case will be turned on end for the liner spraying operation. A robot arm will traverse a vertical beam and spray the liner on top of the white insulation.



Much of the work to date has been directed toward determining the proper chemical composition of the liner. Current plans include a visual inspection of the liner after spraying facilitated by the addition of black pigment to the spray.

The HP9-4-30 steel for the case was selected to be forgeable, machineable, and resistant to stress corrosion cracking and to general corrosion with proper coating. The steel case will be inspected using magnetic particle inspection along with alternative non-destructive inspection (NDI) methods. The consistency of the case properties is dependent on proper process control and development testing. A thorough program of testing to characterize this material is needed to support the finalization of the case design and manufacturing plans. This must include development and characterization of the manufacturing processes such as plasma arc welding and weld repair procedures for the large diameter steel casing.

A key item in the propellant mixing and casting program is the development of the software for the overall process control. Although contracts for development of the software are underway, little attention has been paid to the design of the user interface. It would appear that the system design would benefit from a more complete analysis of the interface and the participation of an expert in human-computer interfaces. As a basis for making decisions, a complete task and functional analysis should be performed.

**Ref: Finding #22**

NASA is committed to using the current aft skirt configuration on all RSRMs

and ASRMs. Data received by the Panel justifies the NASA decision. This data consists of maximum strains recorded at all eight hold-down posts during 18 firings of the Space Shuttle (1 flight readiness firing and 17 actual launches).

Using the data received and a tensile strain of 5,143 micro-inches as the strain measured at 100-percent Design Limit Load (DLL) on the static test specimen, the confidence level in the estimated probability that certain load levels will or will not be exceeded can be calculated:

- The probability that DLL will be exceeded is 5 percent, with a confidence level of 95 percent.
- The probability that 1.28 x DLL will not be exceeded is 99.9 percent, with a confidence level of 99 percent.

Although there is a fair likelihood that the DLL will be exceeded, it is quite unlikely that a failing load will be experienced. In the above prediction, static test failure strength was not corrected to account for variability of weld strength. This variable deserves more consideration. It could be argued that in the large volume of weld material exposed to maximum stresses in the test article, there existed at least one of the maximum flaws that could escape NDI detection. Therefore, failures were initiated at near A-type strength values. The fact that two test articles failed at nearly identical values of load lends some credence to this argument.

Calculated ASRM lift-off loads are within aft skirt certification limits. The

stiffer field joint design of the ASRM versus the pinned joints of the RSRM yields the same factor of safety of 1.28. ASRM flight loads are favorably affected by both the larger diameter of the ASRM case and integrated electronics assembly box relocation.

While a factor of safety of 1.28 is considered adequate, radial biasing on the spherical bearings on the holddown posts is required to achieve it. In addition, there is a study underway to improve the strength of the skirt by adding an external bracket or groove in the skin. Due to the planned use of this skirt on the ASRM, the exceptionally low factor of safety at the skirt weld, and lack of a good understanding of the failure mechanism, NASA's safety organization should continue to monitor strain data from each launch to develop an adequate profile. This will establish a truly credible data base for the statistical justification of the low factor of safety.

**Ref: Finding #23**

It is important to review logistics planning activities early in a program such as the ASRM. Approximately 10 people currently are working on ASRM logistics representing all major contractors and NASA groups. Plans include maintenance, supply and support, transportation, and training. A line replaceable unit (LRU) list has been prepared for flight hardware, and a number of pieces of ground support equipment (GSE) have been identified. Training manual and related document needs have been identified, and transportation barge operations are evolving. A good start on the ASRM logistics has been made.

## **LAUNCH AND LANDING**

**Ref: Finding #24**

During the past year, several Space Shuttle landings either experienced problems or off-nominal performance. Due to the planned increases in landings at KSC rather than Edwards Air Force Base (EAFB), with its relatively large margins for landing error, it is important to understand the reasons behind any landing problems and develop ways to prevent their recurrence.

The STS-37 landing was extremely short and slow. There were many reasons for the extremely low energy state of STS-37 including:

- The crew had never landed on runway 33 at EAFB and had not trained for its approach because it encroaches on Los Angeles International Airport airspace. EAFB runway 33 approach is not included in the simulators.
- The crew were not given the most precise wind-shear information because:
  - Ground controllers were in a high workload situation that was caused by carrying landing solutions for both KSC and EAFB.
  - Information from the Shuttle Training Aircraft (STA) was not passed along adequately; there is no direct communication between the STA pilot and the Space Shuttle crew.

- The crew's belief, which was reinforced by their training, was that they could make up their energy deficit during the post-heading alignment cone portions of TAEM or as part of approach and landing.

STS-39 experienced some tread loss on the right main gear and some nose wheel abrasion. This has been attributed to a faster than normal landing and drift near touchdown. The right gear crossed the crown in the KSC runway twice at high speed, which contributed to the tire wear. The safe limit of the tire (6 plies) was not reached as only three plies were damaged.

There were many lessons learned from analyzing the STS-37 and STS-39 landing anomalies. Some already have resulted in changes in procedures and training. Overall, a heightened awareness of possible landing problems seems to have emerged. A continued focus on communications and decision-making during landing as well as the process of energy management would seem to be warranted.

**Ref: Findings #25 through #30**

The task team concept that has been implemented at KSC is an approach to involving hands-on leadership at the task level. One of its benefits is that it keeps jobs moving without sacrificing quality, control, or safety. It also brings together all personnel needed to perform a particular job in conjunction with an identified leader and places responsibility at an operationally realistic level. Specific training on operating within a task team environment has been developed and used by the Shuttle Processing Contractor (SPC). Task team

leaders are selected from the ranks of engineers and technicians as appropriate.

The task team leader concept has not yet been widely introduced formally into Vehicle Assembly Building operations. However, the operations concerned with solid rocket booster (SRB) stacking and external tank (ET) attachment have developed many similar characteristics. These include a stable workforce that has developed a team approach, authority to accept verbal deviations with subsequent documentation, and direct engineering support and involvement.

In addition to the introduction of task teams, a joint NASA/SPC Steering Committee has been established to oversee and improve launch processing. The Steering Committee developed its "Top Ten" agenda from 250 potential improvements that could be undertaken. As improvements are completed, new targets are to be added to the active list. The general revision of all Standard Practice Instructions (SPIs), underway for the past 6 months, has been a major source of recommended changes that the Steering Committee has pursued. The workforce has been directly involved in these revisions. The objective has been to achieve simplification of SPIs and streamlining of the processes.

Other targets of Steering Committee activity include signature reduction, reduction of witness inspections in favor of greater surveillance and verification, and avoiding steps that do not add value. Additionally, the concept of a designated verifier (where a certified technician hand stamps his/her work such as in airline maintenance/inspection) is being presented to Level I management for acceptance. A shop data collection system is now in place to identify the

sources of delays in Space Shuttle processing. This system, originally planned for inclusion in the Shuttle Processing Data Management System II (SPDMS II), was developed as a stand-alone because of delays in SPDMS II development and implementation. It will be important to ensure that this subsystem as well as others like it that have sprung up to fill specific needs are adequately accounted for in the final SPDMS II design. This can best be accomplished by ensuring involvement of system users in the SPDMS II design and implementation process.

### **LOGISTICS AND SUPPORT**

#### **Ref: Findings #31 through #38**

Although some problems persist, the Space Shuttle support programs are generally in very satisfactory condition.

The Integrated Logistics Panel (ILP) is an essential component of the overall logistics and support activities for the Space Shuttle. In 1991, there were three ILP meetings. At these meetings, presentations were made on subjects germane to the activities of the meeting host site. The wide-ranging issues that were covered in detail included trend management reporting; development of computer tracking systems; control, use, stocking, and disposal of hazardous waste; and interface problems among Centers and contractors. The meetings provide for good working-level integration and interchange on all aspects of the Space Shuttle logistics programs.

The Logistics Management Responsibility Transfer (LMRT) function was initiated to coordinate the transfer of management skills,

equipment, and funding to the KSC vicinity to the maximum extent practical for greater overall launch efficiency. LMRT involves transfer of both NASA and contractor resources. It appears that the present atmosphere surrounding LMRT within the NASA Centers is one of cautious retrenchment, thus slowing the transfer of resources. For example, the memorandums of agreement (MOAs) for transfer of SRB, RSRM, and SSME flight and GSE hardware are all being reevaluated. Other activities, such as thermal protection system, are proceeding as planned. Other issues, such as the Fleet Leader Program to determine the best supportability and repair strategies for the orbital maneuvering system and reaction control system hardware, are being reviewed for transfer to KSC.

This year's work at the NASA Shuttle Logistics Depot (NSLD) concentrated upon meeting the goals for the number of certifications contemplated and on achieving much faster turnaround for component repair and overhaul. However, statistics on the number of certifications completed can be very misleading because some can be completed in 18 months whereas others, like the multiplexer/demultiplexer (MDM), may take as long as 2½ years to perfect using the advanced Automatic Test Equipment (ATE) installed at Cocoa Beach. The schedule calls for the acceptance of six MDM units in 1992 and seven other MDMs in 1993. Although the effort is expensive and time-consuming, there is good reason to believe that eventually an almost routine checkout can be achieved using the ATE.

On the matter of reducing component turnaround time for the combined NSLD

and original equipment manufacturer activity, the latter months of 1991 have shown some illuminating data (Figure 5). The overall workload for repair at the NSLD is now increasing to the point that the backlog is becoming significant. An example of the savings in component repair turn-around time (RTAT) for the rate gyro assembly refurbishment on the SRB shows an average of 105 days versus 160 for the OEM and a cost of \$7,936 versus \$31,000. While not all of the components being repaired or refurbished by the NSLD have shown such spectacular gains, the important issue is that they are now under the control of NASA so that appropriate priorities may be assigned to meet launch supply needs.

Figure 6 shows the history of cannibalizations for recent flights. The controls over the problem have been noted in previous ASAP reports. Whereas about five cannibalizations per vehicle were reported after STS-26, the average number is now down to two. A few repeat items still are involved. For example, TACAN equipment and cables still were being swapped from OV-102 and OV-105 for OV-103 on its recent launch (STS-48). During the last 10 flights with three vehicles in the processing flow, there have only been nine vehicle repairable items, three government furnished equipment items, and eight secondary structural items provided by cannibalization. Overall, this is satisfactory performance for a limited fleet of complex vehicles.

Component RTAT performance is improving with an overall average RTAT through the NSLD of 45 days against a previous 180 days for OEM-handled

components. The NSLD management appears to be working hard to further improve this encouraging performance. One of the problems is that of "streamlining" the paperwork. A typical instance showed a particular part being "logged in" no less than 17 times before reaching the workbench for actual hands-on repair work. Figure 7 shows the repairable line replaceable unit (LRU) fill rate up to STS-42. This parameter is judged to be highly satisfactory at the present time. The overall average fill rate of 92 percent is probably due mostly to improvements in repair cycles.

Finding #37 discusses the "zero balance" (or "none in stock") and those items for which the stock is below the established minimum safe levels. The chart shown in Figure 8 indicates a recent sharp rise probably due mostly to the introduction of OV-105. This problem has the attention of logistics management personnel.

The problem of out-of-production spares, or in NASA terminology "Pending loss of repair/spare capability," can only continue to worsen. In the majority of cases, the principal solution must lie in the extension of NSLD capabilities. Obviously, some components will defy the repair capability of even a well-funded NSLD. With total wear-out of these parts, the only recourse is to institute some redesign and modification action to keep the systems working. Lists of critical vendors and their components are being drawn up. Although this situation is receiving energetic middle management attention, further help may be required from the higher echelons.

The general situation of availability of spare SSMEs (which are supported directly by Rocketdyne out of their Canoga Park facilities) is satisfactory at the present time. The history of cannibalization within the SSME engine shop is shown in Figure 9; the spares requested versus those filled shows a very satisfactory performance. Use of expensive commercial air cargo or other airline charter flights for turbopumps virtually has been eliminated by the introduction of new shipping containers. Current issues including hydraulic actuators, bolt and seal surveillance due to stretched bolts, and nozzle insulation kits, are being handled in routine fashion.

All logistics measurement parameters for the RSRM such as cannibalization, fill rates, zero/below minimum balance, RTAT, and pending loss of spare or repair capability were in the desired range. In addition, Thiokol has full support capabilities at its Brigham, Utah facility. There has been no cannibalization on the RSRM. All repairs of LRUs are done on a "real-time" replacement basis in the Thiokol Wasatch facility. Overall, inventory control accuracy presently is running at 95 percent with a target of 100 percent. This is a very impressive performance.

United Space Booster, Inc., (USBI) handles the SRBs at KSC and in their support facilities nearby. They report no cannibalizations. Fill rate and zero/below minimum balance issues do not arise because production assets are used. USBI can repair all on-site items except the lube oil accumulator; an agreement is being made with an alternative vendor for this item. Only six components have been selected for off-site repair; there are no concerns about support by these

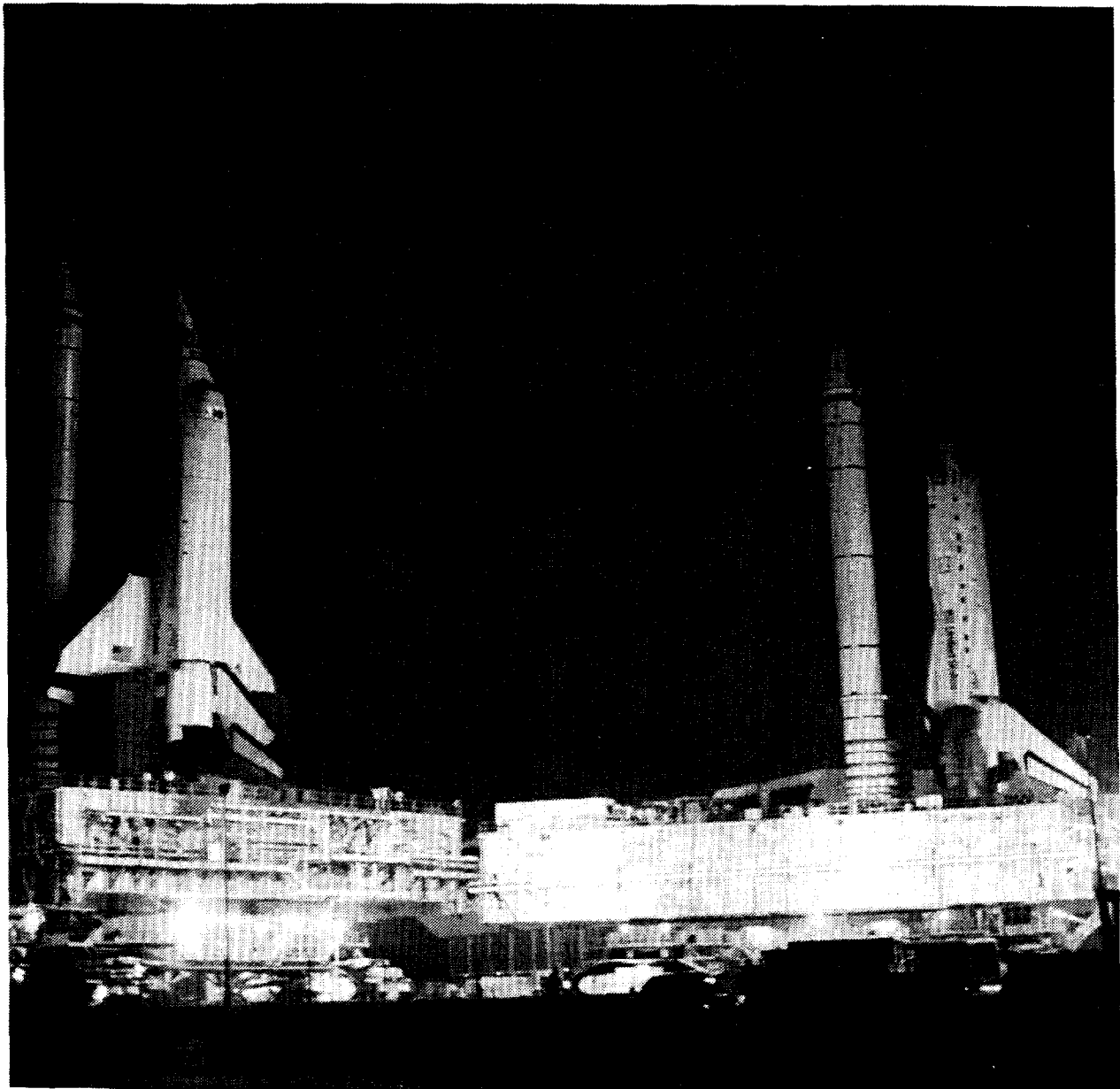
OEMs. RTAT for some elements of the thrust vector control system are lengthy. The paperwork is said to be taking longer than repair of the hardware. USBI is developing their own simple test set for checkout of some of the electrical and instrumentation components to eliminate some of the comprehensive test routines now being accomplished. Off-site repair and recertification is used in the cases of the hydraulic pumps, servo-actuators, and APUs.

A large number of logistics-related annual audits are now being conducted by various agencies such as NASA, the Air Force, and the Department of Defense (DoD). Transfer of selected elements of GSE and commercial consumables is being made from MSFC/USBI to KSC Lockheed Space Operations Co., under the aegis of the LMRT program. An in-production control system (IPCS) is employed by USBI to support the Space Shuttle by minimizing the inventory investment. The IPCS is based on a predetermined flight rate rather than an "initial lay-in" of spares. Considerable economic and control advantages are derived from the IPCS. A state-of-the-art integrated electronics assembly (IEA) test set is being developed at the USBI Slidell facility to perform intermediate and depot-level maintenance. The test procedures are being simplified in the light of experience. The general assessment is that the USBI/SRB logistics and maintenance work is evolving well and is being managed competently. The only concerns appear to be storage capacity and the status of some parts suppliers. A new facility is to be built and will be available in 1994.

ET production and supportability trends appear to be on a steady track with all

parameters in the desired range. Fill rate, zero balance, and below minimum stock are under control. Some pending issues of repair/spare capability are being worked out. There have been no cannibalizations and LRU replacements are declining. RTAT issues present no problems for the ET because items are replaced within 24 to 28 hours from production assets. Overall, performance is very satisfactory.

LMRT activities for the ET are proceeding and the transfer MOA has been approved. Single-source vendor activities on four items are being pursued. An ET GSE plan to recertify every 10 years by analysis, repair, and replacement, currently is being reviewed. ET logistics have initiated state-of-the-art procedures through several dedicated teams including a lively Total Quality Management (TQM) approach.

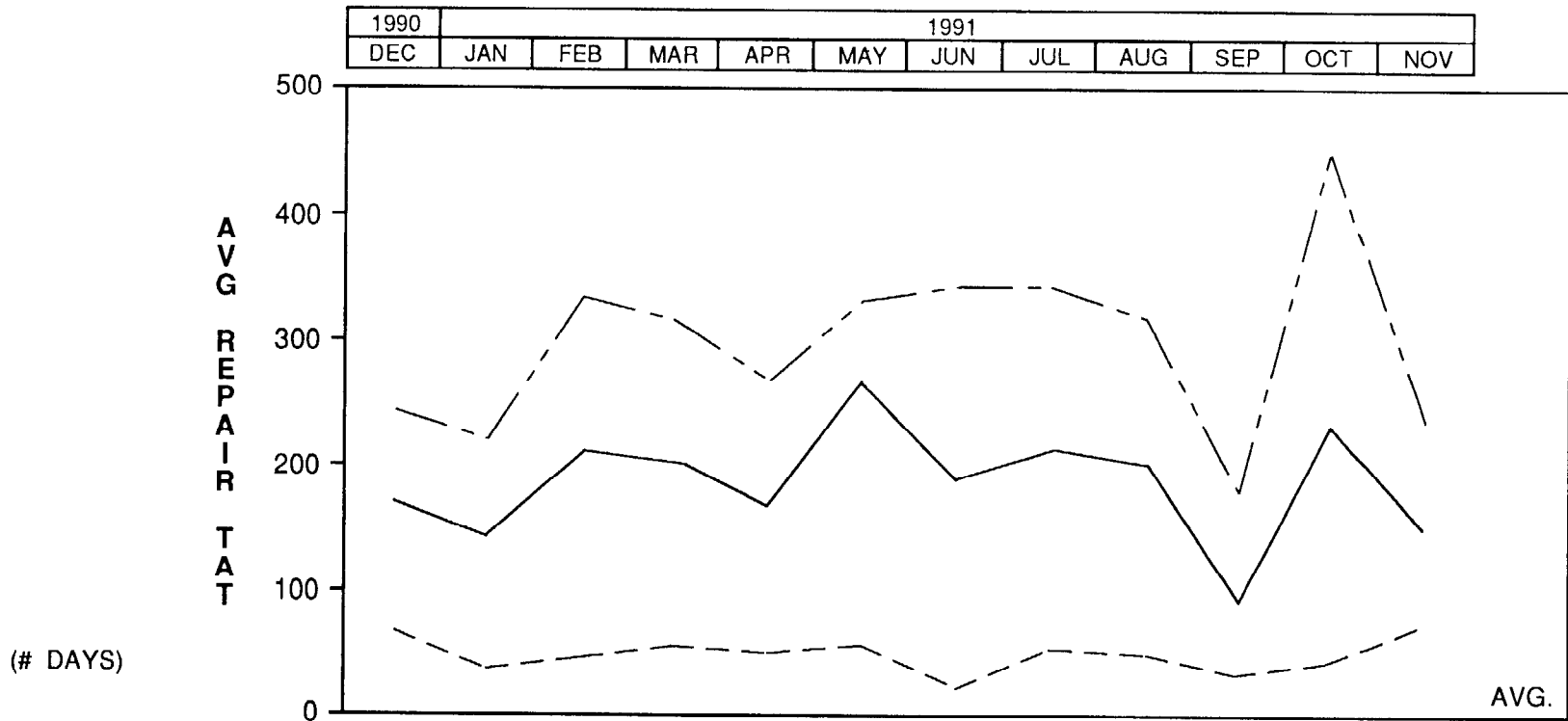


# MAINTENANCE TREND ANALYSIS REPORT

## ORBITER HARDWARE REPAIR PROCESSING

-OEM'S/NSLD REPAIR TURNAROUND TIME (RTAT)

OHRP-3



	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV
OEM'S RTAT	243	220	333	315	268	338	344	342	318	179	*464	233
NSLD RTAT	68	37	46	55	51	55	21	53	52	33	45	71
COMBINED RTAT	170	142	208	204	167	272	188	212	201	93	233	146

### PRR'S COMPLETED

OEM'S PRR's:	35	64	84	78	53	46	62	61	61	36	60	43	57
NSLD PRR's:	25	48	65	58	46	14	58	50	48	52	74	50	49
TOTAL PRR's:	60	112	149	136	99	60	120	111	109	88	134	93	106

NOTE: 1. HISTORICAL FIGURES ADJUSTED PERIODICALLY TO REFLECT REPAIR DISPOSITION CHANGES.

2. \* = RTAT SKEWED OCTOBER 1991 DUE TO EMPHASIS ON CLEARING REPAIRS BACKLOGGED > 12 MONTHS.

NOVEMBER 1991

DATA SOURCE: RIC KSC

Figure 5. Orbiter Hardware Repair Processing



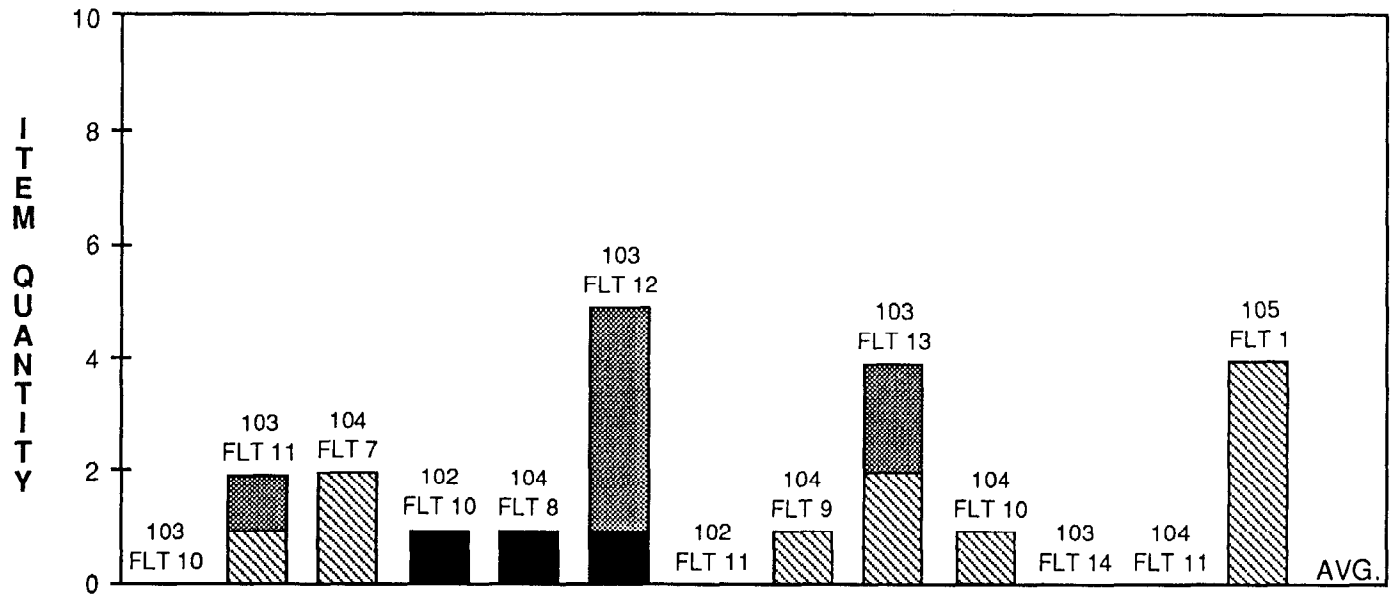
# MAINTENANCE TREND ANALYSIS REPORT

## ORBITER CANNIBALIZATIONS

### VEHICLE & GFE/MISSION KIT CANNIBALIZATIONS

CN-1

STS-31R	STS-41	STS-38	STS-35A	STS-37	STS-39	STS-40	STS-43	STS-48	STS 44	STS 42	STS-45	STS-49
---------	--------	--------	---------	--------	--------	--------	--------	--------	--------	--------	--------	--------



	STS-31R	STS-41	STS-38	STS-35A	STS-37	STS-39	STS-40	STS-43	STS-48	STS 44	STS 42	STS-45	STS-49	AVG.
JSC GFE/MSN KIT ITEMS	0	0	0	1	1	1	0	0	0	0	*0	*0	*0	0.3
VEH REPARABLE ITEMS	0	1	2	0	0	0	0	1	2	1	*0	*0	*4	0.7
VEH NON-REP ITEMS	0	1	0	0	0	4	0	0	2	0	*0	*0	*0	0.7
TOTAL CANNIS	0	2	2	1	1	5	0	1	4	1	*0	*0	*4	1.7

NOTE: \* = INTERIM COUNT AS OF 12-3-91; NOT INCLUDED IN AVERAGE

NOVEMBER 1991

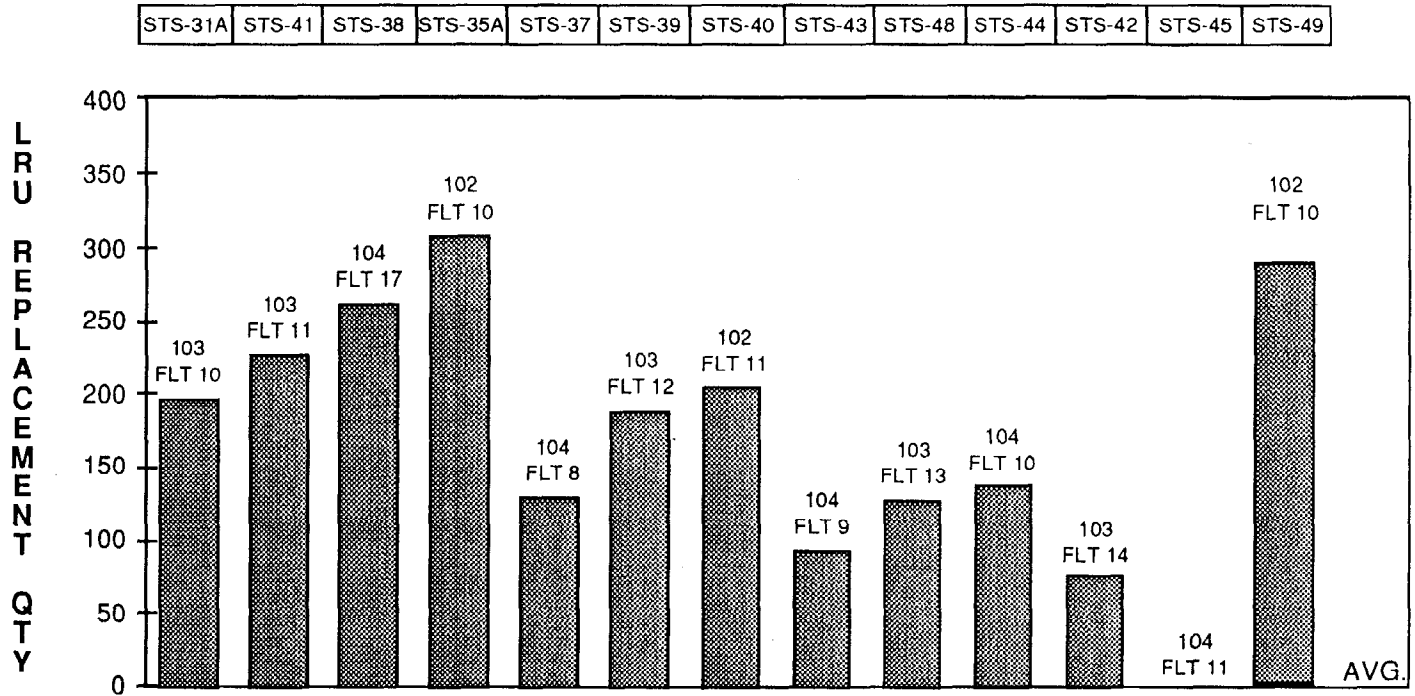
DATA SOURCE: LSOC LOG ENGRG

Figure 6. Orbiter Cannibalizations

# MAINTENANCE TREND ANALYSIS REPORT

## ORBITER REPARABLE LRU FILL RATE BY REPLACEMENT SOURCE

LR-2



Source	STS-31A	STS-41	STS-38	STS-35A	STS-37	STS-39	STS-40	STS-43	STS-48	STS-44	STS-42	STS-45	STS-49	AVG.
FROM CANNIBALIZATION	0	1	2	1	1	1	0	1	2	1	0	*TBD	*4	1
FROM STOCK/RECEIPTS	199	228	262	309	130	190	206	94	128	141	79	*TBD	*281	189
OPEN REQUISITIONS	0	0	0	0	0	0	0	0	0	0	0	*TBD	*2	0
TOTAL	199	229	264	310	131	191	206	95	130	142	79	*TBD	*287	190

% FROM STOCK/RECEIPTS	STS-31A	STS-41	STS-38	STS-35A	STS-37	STS-39	STS-40	STS-43	STS-48	STS-44	STS-42	STS-45	STS-49	AVG.
% FROM STOCK/RECEIPTS	100	99.6	99.2	99.7	99.2	99.5	100	99.0	98.5	99.3	*100	*TBD	97.9	99.5

NOTE: 1. \* = INTERIM FLOW COUNT (AS OF 12-3-91); NOT INCLUDED IN AVERAGE.

2. "FROM CANNIBALIZATION," QUANTITIES INCLUDE REPARABLE ITEMS FROM THE VEHICLE AND JSC GFE/MISSION KIT.

NOVEMBER 1991

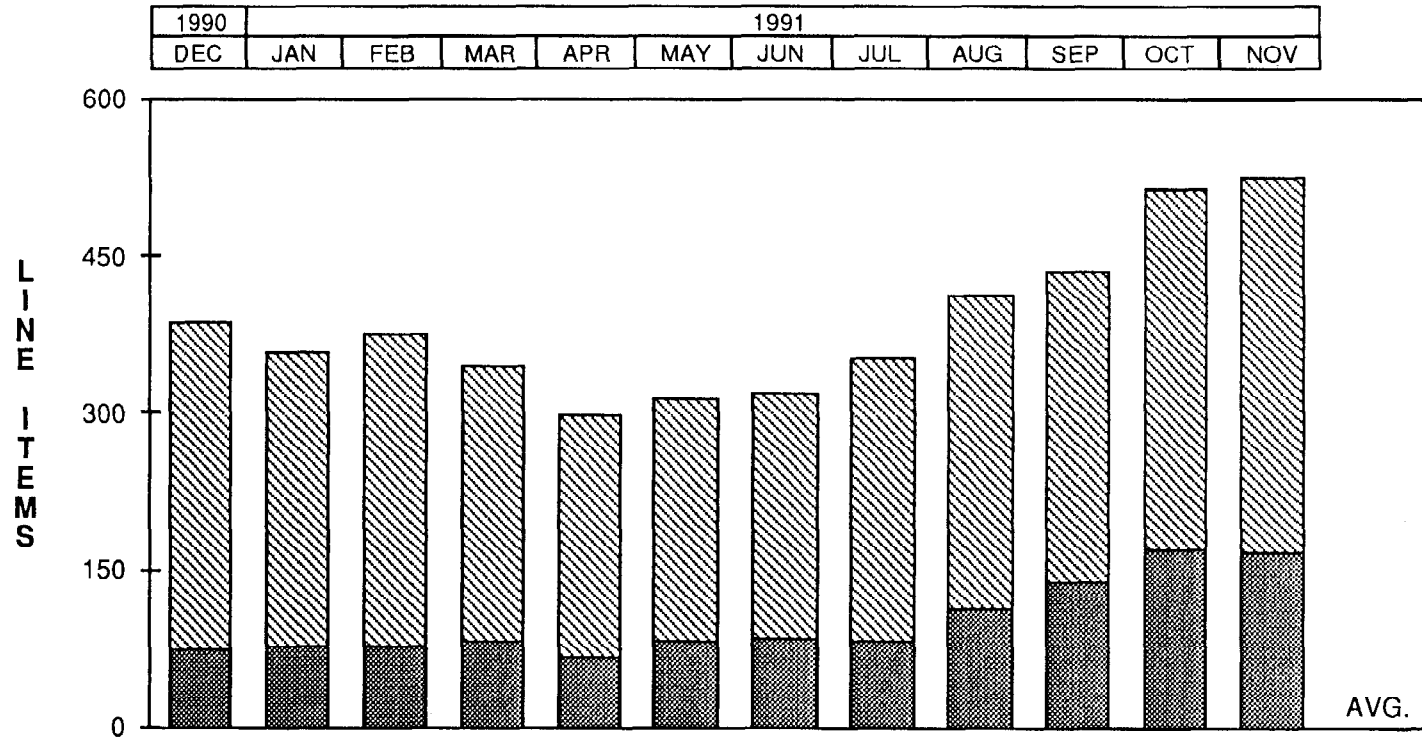
DATA SOURCE: RIC LOG/LSOC LOG ENGRG

Figure 7. Orbiter Reparable LRU Fill Rate by Replacement Source

# MAINTENANCE TREND ANALYSIS REPORT

ORBITER INVENTORY SITE SUPPORT  
 -INVENTORY BELOW ESTABLISHED LEVEL-

ORBINV-3



	1990	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	AVG.
QTY 0 BALANCE	76	80	79	85	69	85	87	84	116	141	172	171	104
QTY BELOW MIN	315	284	301	264	235	235	238	273	301	298	347	357	287
TOTAL	391	364	380	349	304	320	325	357	417	439	519	528	391

Ø BAL ADDED	22	31	21	30	26	34	24	21	40	64	62	55	36
Ø BAL CLOSED	21	27	22	24	42	18	22	24	8	39	31	56	28

NOTE: EFFECTIVE OCTOBER 1991, FIGURES INCLUDE LINE ITEMS PREVIOUSLY MANAGED UNDER SCHEDULE B.

NOVEMBER 1991

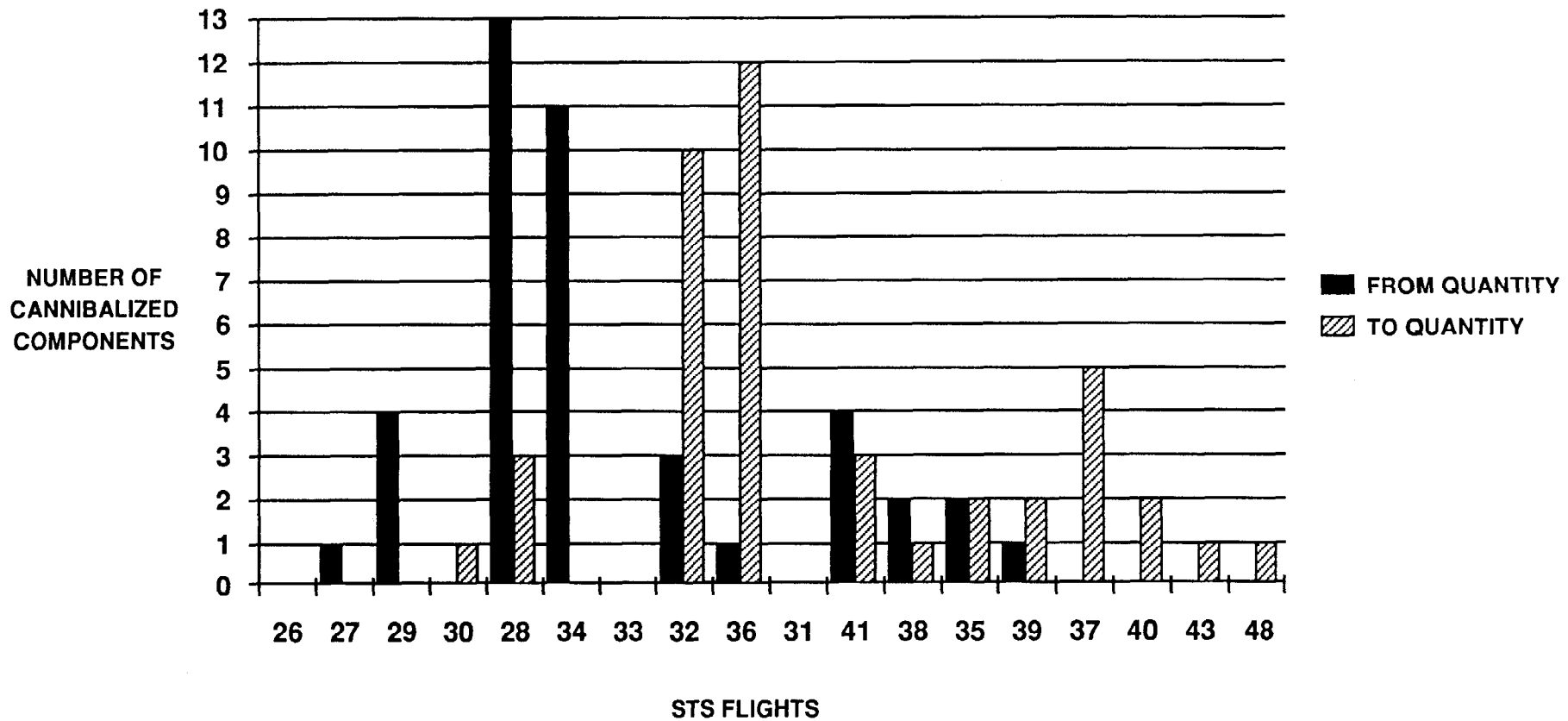
DATA SOURCE: RIC LOGISTICS

Figure 8. Orbiter Inventory Site Support

# SSME CANNIBALIZATION WITHIN ENGINE SHOP

## STS-26 – PRESENT

52



OCTOBER 1991

Figure 9. History of Cannibalization within the SSME Engine Shop

## C. AERONAUTICS

### Ref: Finding #39

On August 12, 1991, NASA Management Instruction (NMI) 7900.2 on aircraft operations management was signed. This NMI deals with critical functions needed to ensure safe administrative aircraft operations. It is understood that a companion delineation of aviation safety requirements in the basic safety manual is contemplated to complete the establishment of a proper aviation safety management organization and Agencywide statement of the philosophy of aviation safety. A Headquarters organization to coordinate flight policies throughout NASA is needed to obtain the maximum operational and safety value from these various policy statements.

### Ref: Finding #40

In the current year, the ASAP only examined the aeronautical flight research programs at the Dryden Flight Research Facility (DFRF). Significant effort also is ongoing at the Langley and Ames Research Centers; the Panel has reviewed these in past years.

DFRF has established an impressive array of test vehicles, which include the X-29s, F-16XLs, SR-71s, F-18, F-15, F-104G, B-52B, T-38, and PA-30. The B-52G is programmed to replace the B-52B. The aircraft are a national asset, and should be maintained and programmed for flight research tests at a high utilization level.

The F-18 High-Angle-of-Attack Research Vehicle (HARV) program includes a massive thrust vectoring

apparatus mounted on the tail section that (with ballast) weighs approximately 2120 pounds. It reduces the maximum Mach number of the F-18 from 2+ to 1.2. The flight control system modifications have been tested in the simulator, and one closed loop (pitch and yaw) flight has been completed. The system currently is cleared to a 20-degree angle-of-attack (AOA) with a potential to trim to a 70-degree AOA. A follow-on activity will incorporate forebody control blowing in the nose for yaw control experimentation.

The X-29 AOA program has completed 85 flights with very stable controllability up to 45 degrees. The vehicle has been flown to 70 degrees; however, loss of vertical tail effectiveness causes a reduction of yaw control above 40-degrees AOA. A strong forebody/wing vortex impinges on the vertical tail. This can cause a fatigue problem and needs to be monitored.

The F-15 Highly Integrated Digital Electronic Control (HIDEC) program has completed 36 flights. It has demonstrated excellent performance gains by implementation of its real-time, adaptive optimization of the flight control, engine, inlet, and engine nozzle. Of great importance is the propulsion-only flight control for landing with no or reduced control of the aerodynamic surfaces. This has application to both civil and military aircraft.

The SR-71B (two-seat) is to be flown for a year to assess and determine a set of research programs than can best be

performed on this aircraft. NASA is fortunate to have been given a wealth of spare parts by the Air Force. Also, the SR-71B had completed its periodic depot maintenance check prior to being assigned to NASA. Two SR-71As have been acquired by NASA and are being placed in flyable storage pending the definition of suitable flight test activities.

The F-16XL aircraft currently is being flown to evaluate the ability to produce laminar flow in the surface of a highly swept (65 degrees on the leading edge) supersonic wing. A portion of the left wing has been fitted with a glove containing suction holes for removing the boundary layer. A turbo-compressor is mounted in the fuselage to produce the wing suction. Concerns were expressed over the potential for turbine wheel failure with potential ensuing damage to the aircraft. The flight tests were begun in March 1991.

The B-52 currently is being used as a launch vehicle for the Pegasus space vehicle. The first two of the planned six flights have been accomplished successfully. The gross weight of the Pegasus is approximately 42,000 pounds, which is well within the load carrying capability of the NASA B-52 pylon that previously was used to launch the X-15 aircraft.

Another interesting test program utilizes the Convair 990 aircraft for dynamic tests of the Shuttle landing gear. The Orbiter speeds and weights can be duplicated to evaluate tire wheel performance on various landing surfaces.

Overall, the assessment of the ASAP is that these programs are being managed with an acceptable emphasis on flight safety through a rigorous process of analyses and safety reviews.

## D. OTHER

### Ref: Finding #41

Reports from crew members on extended Space Shuttle missions that involved two shift operations indicated that they experienced some difficulty in achieving restful sleep. This phenomenon is not unusual when circadian rhythms must be shifted. These problems are similar to those experienced by aircraft flight crews in long-haul operations. A program of research and countermeasure development on crew rest cycles and circadian rhythm shifting to support both Space Shuttle and Space Station operations is needed to address this problem. This program could productively be modeled after the ongoing NASA aircrew research being conducted at the Ames Research Center (ARC).

### Ref: Finding #42

In analyzing the causes of aircraft accidents and near accidents over the last decade or more, case investigators have come to rely increasingly on clues furnished by experts in human engineering. Individualistic behavioral patterns performed under stress, in some instances, have been identified as prime contributors to the accidents. Extensive worldwide military and civil aviation has provided a broad data base for such analyses. In contrast, the data base for manned spaceflight and associated ground operations is relatively small and of recent origin. As a consequence, little interest has been shown in harnessing this discipline to spaceflight programs. Nevertheless, as Space Shuttle flight duration is increased to 30 days or more, and SSF is activated, the potential for

accidents attributable to human error will increase. For example, sleeplessness and boredom have been highlighted as the reason for several airplane accidents. Therefore, the time may be opportune to enlist the insights of human engineering to help prevent accidents in the manned space programs attributable to such situations.

NASA possesses competent in-house capabilities in human engineering, especially at ARC and JSC. ARC, in particular, has made frequent contributions affecting aviation safety whereas JSC's role principally has involved astronaut's experiences in spaceflight. Coordination and information exchange between these two Centers has not been as effective as it might be; this is partially due to the different programmatic responsibilities. However, with the beginning of operational planning for SSF, NASA should bring about a closer relationship between these programs and potentiate efforts to enlist human factors research as an agent to prevent human errors in space activities.

### Ref: Finding #43

NASA has a hierarchy of reporting systems for mishaps and incidents. Formal documentation, including NMI 8621.1, which is currently in revision, defines the various levels of mishaps and investigation and reporting requirements. At the top level, NASA operates the NASA Safety Reporting System (NSRS). Although named and modeled after the Aviation Safety Reporting System

(ASRS), that NASA runs for the FAA, NSRS is not its analog. ASRS was designed to provide data on near-misses and human errors in the aviation system (pilots, controllers, and mechanics), which otherwise would have gone unreported because they did not result in property damage, injury, or a detected violation. It is a voluntary system of self-reports with the reporter being granted limited immunity in some cases.

NSRS was developed in the aftermath of the Challenger accident to provide a direct line to NASA top management so that people in the system at any level could surface a safety concern if they believed it to be of sufficient importance. It perhaps is unfortunate that NSRS was named after ASRS because their objectives are quite different.

Even though it is lightly used, NSRS provides a valuable service by providing a potential safety valve for reporting Challenger-like situations. However, NASA has no system analogous to ASRS that allows people to report their own errors or near-errors in an anonymous manner *at the local level*. The new task team approach emerging at KSC encourages some reporting of this type but appears neither to structure it nor to provide any expert analysis of the information collected.

NASA is lacking a mechanism for reporting those events in which an error happens and is recognized by the person involved or an observer but does not result in a defined accident, incident, close call, or reportable violation. For example, a technician working on a fuel cell might momentarily cap a vent line that is not to be capped but immediately realize his/her error and remove the cap

before any damage occurs. Likewise, someone may start to turn a bolt the wrong way but realize the mistake before the action takes place. These types of situations do not get attention unless someone involved perceives a fix. In this case, a suggestion may be generated to management in the hope of receiving some recognition. Otherwise, the situation goes largely unreported.

Because the existing reporting systems go outside the local environment (e.g., to Safety or to Center or Headquarters management) it is likely that a "near-error" is perceived as too inconsequential to warrant a report. This is exactly the opposite of the ASRS situation in which pilots, controllers, etc., have been encouraged to make a report of any such event, no matter how insignificant it seems. Trained analysts then can look across events for patterns indicating an emerging problem or within a particular occurrence for possible remedies.

The clear benefits from collecting information on human errors does not imply that an additional, highly structured reporting system is required. Inclusion of a training module for task teams and quality working groups might be sufficient if a way were devised to amass and analyze the information over time. The major benefit of systems such as the ASRS is that they permit trained analysts to spot emerging safety problems and trends before they lead to accidents.

#### **Ref: Finding #44**

There were two indications of a quality control problem having to do with the Tethered Satellite System (TSS) program. The first occurred when a



spare clutch to the vernier motor failed its acceptance test due to the failure of bonding between the rotor and the cork clutch material. The shelf life of the bonding had been exceeded. A question exists regarding the flight clutch because the bonding material shelf life is uncertain. Investigation revealed that neither the flight article nor the failed spare unit had an adequate build paper with quality assurance acceptance. There are two other flight clutch assemblies that do possess the proper documentation.

The primary control of the trajectory of the TSS is the rate of extension or retraction of the tether. Since an accurate analytical prediction of the system dynamics is directly related to the ability to control roll, all components of the system, including the clutch, should be without operational uncertainties.

The other problem involved a shipment of 15-5 stainless steel material that was marked incorrectly as not needing heat treatment. It was used erroneously to manufacture 18 parts in the mechanism that deploys the TSS. Therefore, these 18 parts have a lower hardness and strength than was intended -- assuming they had been heat treated. Initial investigation by NASA and Martin Marietta indicate the parts will not have a critical impact on the operation or safety of the TSS.

**Ref: Findings #45 and #46**

Current plans for long-term use of the Space Shuttle, and assembly and operation of the SSF suggest a continued and increasing need for extravehicular activities (EVAs). Although excellent efforts have been mounted and are ongoing to reduce the need for EVAs

whenever possible, contingencies, design requirements, and economics each will dictate the need for some EVA activities. These EVAs must be supported by an appropriately designed extravehicular mobility unit (EMU) and associated space suit. For example, current projections for the on-orbit repair of the Hubble Space Telescope (HST) call for three separate EVAs, each lasting over 6 hours. This is a more ambitious EVA profile than previously has been attempted.

As the demand for both the number and duration of EVAs increases, the benefits possible from an improved EMU and suit to support them become clear. Existing suits and their associated portable life support system (PLSS) have several characteristics that limit their flexibility and utility. They operate at low pressure thereby requiring extensive prebreathing of pure oxygen to avoid problems associated with nitrogen bubbles in the blood ("the bends"). This could be severely limiting if an emergency EVA or an EVA evacuation is needed from the Space Station. Even if sufficient prebreath time is available, this activity places additional workload on the EVA crews, which might be more productively allocated to the EVA activity. This, in turn, could potentially reduce the number of EVAs required because crew members could work more productively and accomplish more on each EVA. In addition, the refurbishment and sizing of the existing suits is extremely time-consuming and labor intensive and can now only be fully accomplished on the ground.

NASA already has explored the technology needed to overcome these problems. Two programs, the AX-5 at the ARC and the Mark 3 at the JSC,

have built and tested prototype suits that do much to overcome the problems inherent in the current design. Neither the AX-5 nor the Mark 3 are complete solutions to all of the problems inherent in having humans work in space. However, they successfully have demonstrated that a more flexible design capable of on-orbit maintenance and sizing and eliminating or reducing prebreathing requirements is possible. They have further demonstrated that there are no significant technological issues associated with producing these improvements.

Existing budgetary constraints have prompted the deletion of most funding for completing development of an advanced suit and EMU. Because the existing suits continue to perform satisfactorily on Space Shuttle missions, a decision to defer some or even most of the costs of developing a new suit is not unreasonable. However, it is clear that the ultimate implementation of SSF can be greatly enhanced by an improved suit design. Therefore, NASA should commit to specification and development of a new suit, and establish its implementation schedule consistent with budget availability. One possible pathway to upgrading the suit design

would be to couple the existing PLSS with a new suit based on AX-5/Mark 3 technologies. The PLSS could be modified to operate at a higher pressure to reduce prebreathing time and take maximum advantage of the design qualities of the new suits. As funds and time permit, the PLSS could be replaced with an upgraded EMU that could be based, in part, on lessons learned from the already planned extended EVAs for HST repair and Space Station assembly. It also would seem wise for NASA to support the research necessary to characterize more fully the bends risk associated with micro-gravity EVA activities. Existing tables relating prebreathing time and atmospheric pressure are based on pressure chamber and deep sea diving experience. While these are good analogies, they ignore the influence of micro-gravity and the exertion levels expected of EVA astronauts. NASA has the research expertise and the data collection opportunities during on-ground simulations and Space Shuttle flights to collect the data necessary to clarify this issue. A potential side benefit of conducting this research would be a significant clarification of the need for and use of hyperbaric airlocks on the Space Station.



#### IV. APPENDICES

**APPENDIX A  
NASA AEROSPACE SAFETY ADVISORY PANEL MEMBERSHIP**

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Aerospace Consultant  
Former Vice President, Engineering  
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Staff Assistant

**APPENDIX B  
NASA RESPONSE TO MARCH 1991 ANNUAL REPORT**

**SUMMARY**

In accordance with the Panel's letter of transmittal, NASA's response dated June 17, 1991, covered the "Findings and Recommendations" from the March 1990 Annual Report.

Based on the Panel's review of that response and the information gathered during the 1990 period, the Panel considers that the following 3 of the 34 original items noted in the June 17th response are "open" at this time:

<u>Finding/Recommendation No. and Subject</u>	<u>Comments</u>
#2 Space Shuttle Autoland System	The Panel will continue to follow the Autoland progress.
#4 Space Shuttle Software Verification and Validation	The Panel will revisit this system.
#10 Integration of ASRM/RSRM Plan	Schedule problems warrant Panel review.



National Aeronautics and  
Space Administration

Washington, D.C.  
20546

Office of the Administrator

JUN 17 1991

Mr. Norman R. Parmet  
Chairman  
Aerospace Safety Advisory Panel  
5907 Sunrise Drive  
Fairway, KS 66205

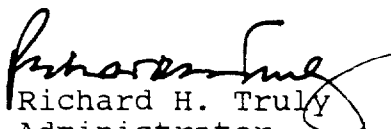
Dear Mr. ~~N~~ Parmet:

In accordance with your introductory letter to the March 1991 Aerospace Safety Advisory Panel (ASAP) Annual Report, I am enclosing NASA's detailed response to Section II, "Findings and Recommendations."

The dedication of the ASAP members to NASA continues to be commendable. Your recommendations have helped reduce risk and improve safety in NASA manned/unmanned programs and projects. Your efforts are greatly appreciated.

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

Sincerely,

  
Richard H. Truly  
Administrator

Enclosure

## FINDINGS AND RECOMMENDATIONS

### A. SPACE SHUTTLE PROGRAM

#### **SPACE SHUTTLE ELEMENTS**

##### **Orbiter**

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

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

***NASA Response:*** Concur. Modifications are scheduled for each vehicle's Orbiter Maintenance Down Period (OMDP). The OMDP has been incorporated into the Space Shuttle Program to provide dedicated times for performing detailed vehicle structural inspections, subsystem inspections and internal functional checks as well as modifications. All vehicle modifications will be complete by mid-1993.

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

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

***NASA Response:*** Concur. The existing Shuttle autoland system is certified and is a reliable backup for 16-day Extended Duration Orbiter missions. A significant program to collect crew performance data is being undertaken by the Office of Space Science and Applications during flights involving incremental increases of on-orbit duration. Current plans involve flying four 10-day flights and three 13-day flights prior to the first 16-day flight. Crew performance data will be evaluated and must be judged acceptable prior to commitment to the next increment of extended duration.

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

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

**NASA Response:** Concur. NASA has just completed integrating the Improved General Purpose Computer (IGPC) into the fleet. This upgrading of the orbiter computers included an extensive reverification of the flight software. Integrated testing of the flight hardware and software was one of the milestones in the certification of the IGPC hardware and flight software. In addition, the Shuttle software is incrementally upgraded and released for flight approximately every eight months. These upgrades are validated, verified, and certified through an extensive and thorough process. Future computing capability beyond recent incorporation of the IGPC is under development in the Assured Shuttle Availability (ASA) Program in the Multifunction Electronics Display Subsystem (MEDS). The plan for the subsequent 10-15 years involves maintaining the existing system. Issues involving obsolescence and enhanced performance will continue to be reviewed.

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

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

**NASA Response:** Concur. An independent review has been completed of NASA's entire software generation, verification, validation, object code build, and machine loading process. As part of the post-51L activity, NASA contracted with Intermetrics Inc., as the independent verification and validation (IV&V) contractor. NASA is developing a policy to define the scope of our independent oversight activity. To assist in this task, NASA has requested the National Research Council to perform an independent review of the IV&V process to include software generation, object code build, and machine loading.

#### **Space Shuttle Main Engine (SSME)**

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

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

**NASA Response:** Thank you. We intend to maintain a good posture on spare engines.

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



*number of allowable reuses between overhauls. Premature combustion chamber cracking and injector erosion were experienced with the two-duct powerhead.*

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

**NASA Response:** Concur. The SSME Project is continuing certification of both the 10K pumps and development of the two-duct powerhead through hot-fire testing at SSC and detailed engineering reviews of the test results. This effort will continue to develop these safety improvements for incorporation at the earliest possible time.

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

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

**NASA Response:** Concur. In recent weeks, component-level testing for the alternate turbopump development (ATD) program has provided improved testing results. Using SSC testing to supplement component testing will add to the fidelity of the component testing program. The ATD Test Program will not truncate or compromise the objectives and thoroughness of the planned component testing.

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

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

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

**NASA Response:** A factor of safety of 1.4 is not necessary for the Redesigned Solid Rocket Booster Aft Skirt since the loading of this structure is well understood. The Space Shuttle Program has been operating the current Solid Rocket Booster (SRB) with an aft skirt factor of safety of 1.28. The current radial biasing of the Spherical Bearings assures that this 1.28 factor of safety is achieved. Additional radial biasing, improved loads definition, and possible structural modifications, are being studied for their potential to further increase the factor of safety for the ASRB.

Small inward biasing of the pedestal spherical bearings has been used successfully since STS-28 as a means of increasing structural factor of safety. The biasing imparts a

compressive preload in the area of the critical aft skirt weld, thus helping to offset the tensile load induced there during SSME Thrust Build-up.

Efforts are also underway to improve even further the definition of Aft Skirt loads. Strain gauge instrumentation on skirts has provided an extensive data base since STS-26 and such data gathering will continue on the current SRB. An improved definition of ASRB Aft Skirt Loads will be available as the ASRB Structural Models are developed. Also, structural modifications are being studied that will enhance the load carrying capability of the skirts for the ASRB. With biasing and structural modifications, the aft skirt factor of safety will be maximized, but achieving a safety factor of 1.4 is not an absolute requirement.

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

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

***NASA Response:** Concur. NASA is incorporating enhancements in the Thiokol Redesigned Solid Rocket Motor manufacturing facilities and processes in the areas of propellant mixing, casting, and in final assembly operations. These enhancements involve new facilities for automated propellant premix, sample casting, a modified oxidizer facility, and new propellant analysis equipment. For final assembly, there will be a new six-bay segment processing building with vertical nozzle installation capability and other handling improvements.*

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

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

***NASA Response:** Concur. An integrated plan to govern program transition from SRB Operations to ASRB Operations is under development. This plan will show how Space Shuttle Program goals will be met within the technical constraints involved in integrating a new element into Shuttle operations. The development of the SRB-to-ASRB transition plan is scheduled to be completed by July 1991. Once complete, this transition plan will be incorporated into the System Integration Plan and controlled at Level II. This will ensure that any proposed changes to the transition plan will receive total program review.*

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

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

**NASA Response:** The ASRM Program cost/schedule is under review as Congress considers the FY 92 Budget request. Our desire is to have a reasonable allowance for schedule reserve, but budget pressures will likely drive us to a somewhat success oriented schedule where further schedule margin will have to come from first flight date.

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

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

**NASA Response:** Concur. A 1-year overlap of RSRM and ASRM is planned to cover contingencies. While the degree of automation planned for the ASRM manufacturing facilities is ambitious, the process development involves an acceptable degree of schedule risk. Since construction of facilities and development of the manufacturing processes precedes the design verification phase of the program, any schedule delays would occur at a time when adjustments to extend the use of the RSRM can be made.

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

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

**NASA Response:** Relocating the T-97 Test Stand Hardware to Stennis Space Center (SSC) is being considered as a cost-effective means of meeting the combined testing needs of the RSRM and ASRM Projects. It has been determined that neither the ASRM or RSRM test stands require dynamic (side load) test capability. This plan leaves the T-24 Test Stand at Thiokol for RSRM tests and moves the T-97 Test Stand (without dynamic capability) to SSC for ASRM.

#### **External Tank (ET)**

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

**Recommendation #14:** Keep up the good work.

**NASA Response:** Thank you.

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

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

**NASA Response:** Strongly concur.

### **Launch And Landing Operations**

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

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

**NASA Response:** Concur. KSC and the Shuttle Processing Contractor (SPC) are continuing to try to reduce incidents, even beyond the success we have had to date. We are accomplishing this through a network of preplanning, communication, and coordination that encourages everyone to work together and understand that they are an essential part of the task at hand. Management takes no punitive action against any worker for incidents unless it is clearly shown that the worker had a preconceived negative intent or makes the mistake repetitively (more than twice). For repetitive errors, the worker is simply reassigned to other tasks and/or retrained. Any repetitive error is automatically evaluated from the human factors viewpoint. It should be noted that human factors concepts have been used throughout the creation and verification of all Orbiter Maintenance Instructions (OMIs) and the initial performances of all tasks involved in vehicle processing. With quality control checks at all levels from planning, engineering, OMI creation, and progressive steps of task team work, we are practicing TQM and reducing incidents. We will continue to use enhanced TQM and a broader use of human factors, as appropriate.

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

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

**NASA Response:** Concur. NASA is very concerned about the potential that such a perception may exist. KSC and SPC have instituted a program of vertical and lateral communications that extends from the highest KSC management levels (both civil service and SPC) down through middle management, engineering, and the task team technical floor workers. Practices include weekly meetings at top management levels, daily reviews at middle management and throughout engineering, and per shift (or more) coordination sessions at the task team level. There are also horizontal channels for coordination from hands-on-workers, logistics/supply elements, and support operations. It is continually stressed throughout these channels that disciplinary action for errors will not be severe or punitive unless the errors or incidents result from clearly proven negative intent. All employees are advised of their obligation to come to work fit and able, and to perform the tasks carefully and successfully. Any error is discussed with the responsible employee and efforts made to help him or her understand how to avoid a repetition.

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

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

**NASA Response:** Concur in principle. The ASAP is correct in suggesting that there are continuing waivers where the specification can be changed; a good example is the tumble valve. Based on Flight Data for tanks with an active tumble system, the tumble systems were disabled on selected flights based on analysis of External Tank (ET) Rupture Altitude and the corresponding debris footprint. Flight and tracking data were used to determine the correlation between non-tumble system tank trajectories, ET motion, ET Rupture Altitude and the ET Debris Model. Based on these analyses and flight tests, the applicable specification was changed to preclude the necessity for continuing ET Tumble System Waivers. However, it should be pointed out that waiver disposition is never "routine." As outlined above, a request for waivers or to change a specification requires rigorous supporting data (many times flight data) presented through a series of at least three change control boards. Specifications have been, and will continue to be, changed where it is proved that the limits should be revised for all flights.

## Mission Operations

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

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

***NASA Response:** Concur. Since 1986, NASA has been in a phased process of upgrading the operational elements of the Mission Control Center (MCC) to incorporate advanced technology. This includes the replacement and upgrade of mainframe computers, and the placement over the last 2 years of current generation workstations in the MCC that are capable of using advanced techniques for analyzing and displaying data. These enhancements are part of a comprehensive multi-year plan developed to introduce new technology into the operating environment.*

## **ASSURED SHUTTLE AVAILABILITY PROGRAM**

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

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

***NASA Response:** The Space Shuttle Program considers safety changes to be the responsibility of the baseline program and funds are made available to implement these changes. A recent example is the modification of the Orbiter External Tank door fixture. This modification was not planned nor budgeted, but was immediately implemented.*

The objective of the Assured Shuttle Availability (ASA) Program is to keep the Shuttles flying well into the 21st century. The program addresses supportability, maintainability, and safety margin issues. Previously ad hoc programs will be combined in the future into a structured program that will prioritize candidates and manage the programs with managers whose primary function will be development programs.

The current approved programs include the Multifunction Electronics Display Subsystem and the Hardware Interface Module. These programs are primarily obsolescence (supportability) programs. The other approved program, SSME Advanced Fabrication, replaces main engine obsolete manufacturing techniques by using castings versus weldments. The goal is to reduce cost and eliminate many Criticality 1 failures. The

Space Shuttle Program will continue to manage safety enhancements. The ASA Program primarily will provide program supportability, but also will increase safety margins, where applicable.

## **LOGISTICS AND SUPPORT PROGRAM**

***Finding #21:** The Orbiter logistics and support systems are continuing to evolve satisfactorily. The expansion of component overhaul and repair facilities at the launch site and in the nearby areas is most impressive. Liaison between all NASA Centers and contractors appears to be excellent, and the control and communications networks are being further improved.*

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

***NASA Response:** Concur. Thank you.*

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

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

***NASA Response:** Concur. Turnaround times continue to receive NASA management attention. KSC logistics personnel frequently review with the logistics contractor those items that have been in the repair process for longer than 180 days. These reviews provide an incentive for the logistics contractor to ensure that vendor repairs are not delayed for other than engineering concerns. In addition, the transition of repair capability from the original equipment manufacturers (OEMs) to the NSLD will continue to shorten overall turnaround time. The overall turnaround time for the last 3 calendar years has decreased significantly: 194 days in 1988, 174 days in 1989, and 155 days in 1990.*

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

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

***NASA Response:** Concur. There are still a few shortages of high-value and long-lead items. These shortages are being addressed either through modification/improvement programs (as for the APUs) or through additional procurement (as for the reaction control system thrusters).*

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

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

**NASA Response:** Concur. NASA recognizes the potential problem posed by obsolete parts. KSC has instituted a three-part program to minimize the impact that obsolescence could have on orbiter logistics supportability. The program includes identification of potentially obsolete parts; evaluation of available prevention options; and tracking of obsolescence data, including actions taken. These actions are taken in conjunction with the Assured Shuttle Availability Program. The increased emphasis on parts obsolescence should ensure the ability of KSC to provide up-to-date hardware for orbiter launch processing.

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

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

**NASA Response:** Concur. The Space Shuttle Program has developed and instituted a plan by which the orbiter vehicles are inspected and modified every 3 years. This plan involves the use of specific orbiter flow periods commonly referred to as Orbiter Maintenance Down Period (OMDP) to perform vehicle structural inspections and modifications. The orbiter structural inspection will verify the integrity of primary structural elements of the vertical tail, flight control surfaces, aft fuselage, mid-fuselage, landing gear, crew module and forward fuselage. Critical elements will be inspected for corrosion, fatigue, deformation and cracks, which would result in reduced structural integrity. Flow periods of 188 days have been allocated for an OMDP. OV-102 is the first vehicle to be scheduled for an OMDP and will begin in FY 91. OV-103 and OV-104 are currently scheduled to begin their modification/inspections periods in FY 92. The Space Shuttle Program will continue to use OMDP's to inspect and modify each orbiter throughout a vehicles operational lifetime to ensure each orbiter's structural integrity and upgrade the systems as required to ensure operations through 2020.

## **B. SPACE STATION FREEDOM PROGRAM**

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

**Recommendation #26:** The purpose and funding of the redefined Space Station Freedom Program must be firmly agreed upon by the Congress and NASA. Then, NASA should be permitted to organize and manage the program. Systems engineering,



system integration, and risk management must be integral and vital parts of the revised program.

***NASA Response:*** Concur. The restructured Space Station Freedom program plan successfully responds both to the guidance of the Congress on funding and function and to the recommendations of the Advisory Committee on the Future of the U.S. Space Program, the Augustine Panel. The restructured plan enjoys strong support from the Administration and from many elements of the Congress. This consensus should permit NASA to go forward with a stable program and a consistent interaction of engineering design and risk management.

## C. AERONAUTICS

### **AIRCRAFT OPERATIONS**

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

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

***NASA Response:*** Concur. The responsibilities for aviation safety and aircraft operations have been clarified. New management instructions have been drafted to document the responsibilities. These instructions are in their final coordination phase. NASA *will* follow through with the implementation of these policies.

### **RESEARCH AND TECHNOLOGY**

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

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

***NASA Response:*** Concur. Flight test results will be documented thoroughly, and findings and lessons learned will be disseminated NASAwide. Aeronautical Research Flight Test Programs in NASA will continue to be the model for safe and efficient experimental flight testing for the U.S. aviation community. Safety will continue to be the most important principle in our research and testing programs, and this philosophy will be clearly presented in all related documentation.

## D. SAFETY AND RISK MANAGEMENT

### MISSION SUPPORT

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

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

***NASA Response:*** Concur. Fault-tree analysis (FTA) and Failure Modes and Effects Analysis (FMEA) are techniques fundamental to the NASA systems engineering disciplines. They are used throughout system development to enable early identification of problems, and assign hardware and software criticality. Critical Item Lists (CILs) are tabulated by criticality level and require review, resolution, or waiver before flight is approved. FTA is used by the safety organizations to provide top-down analyses of safety-critical problems, while the FMEA is a bottom-up approach that begins at the parts level. Both formal and informal on-the-job training in these techniques is provided.

### TOTAL QUALITY MANAGEMENT (TQM)

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

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

***NASA Response:*** Concur. NASA's ongoing emphasis on quality and productivity improvement (QPI) began in 1982, with an internal and external focus. In 1986, a special emphasis was placed on the external efforts in recognition that the majority of the NASA budget is allocated to contractors. In fact, Martin-Marietta/Michoud (which was referenced in the ASAP report) was evaluated under the NASA Excellence Award Program and won in 1987 for their quality achievements. In 1989-90, a renewed emphasis was placed on internal QPI programs, while still maintaining our external efforts. In February 1990, NASA formally launched an internal TQM initiative, and recently conducted a NASAwide TQM assessment. We are now planning an internal TQM evaluation initiative patterned after the George M. Low Trophy (NASA's Quality and Excellence Award program) using TQM criteria contained in the President's Award for Quality and Productivity Improvement. NASA top-level management is committed to successfully implementing the TQM program and will be directly involved in

formulating strategies for achieving NASA TQM program goals. The TQM Steering Committee, consisting of NASA senior management, will report on the status and progress of TQM implementation at their Fall 1991 meeting.

### **SAFETY REPORTING SYSTEMS**

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

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

***NASA Response:** Concur. NASA is investigating the human element in all NASA mishaps. Efforts are currently underway to refine and update NMI 8621.1E. Part of this effort will be the transition of NASA Mishap Investigation Board Membership requirements to the Basic Safety Manual, NHB 1700.1. Consideration will be given to incorporating a requirement to have a Human Factors Engineering professional assigned to a NASA Mishap Investigation Board during this transition. The NASA Headquarters Safety Division is sponsoring a Human Error Avoidance Project at KSC that includes funding for a full-time Human Factors Engineering professional. This individual will be available to participate in future mishap investigations at KSC. Formalization of the NASA close-call investigation process is also a NASA concern. The update to NMI 8621.1E will stipulate investigation of Type A, B, and C mishap-related close-calls as a requirement in the Basic Policy for NASA Mishap Reporting and Investigation. Under the current policy, all close-calls must be reported; close-call reports are evaluated at NASA Headquarters and, when necessary, an investigation board is established.*

## **E. OTHER**

### **NASA FACILITIES**

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

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

***NASA Response:*** Concur. There should be a continuing focus on the importance of preserving and periodically updating the physical plants and research facilities at the NASA Centers. NASA's current efforts emphasize the rehabilitation and modernization of their 40- to 50-year-old wind tunnel facilities.

#### **EXTRAVEHICULAR MOBILITY UNITS/SPACE SUITS**

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

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

***NASA Response:*** Concur. The planning and design for the Space Station Freedom (SSF) and other manned programs should minimize extravehicular activity (EVA). Subsequent to the SSF External Maintenance Task Team (EMTT-Fisher-Price) study, the External Maintenance Solutions Team (EMST) was formed to evaluate EMTT findings/recommendations and provide further recommendations for mitigating EVA requirements. Many of the EMST recommended actions were incorporated by program management and additional actions were developed during the restructuring activity; other recommendations are still being evaluated. NASA concurs that development of an improved Extravehicular Mobility Unit (EMU)/Space Suit is desirable but budgetary constraints preclude pursuing that activity at this time. Two candidate designs for the EMU have been studied at the Johnson Space Center and Ames Research Center.

#### **TETHERED SATELLITE SYSTEM (TSS)**

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

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

***NASA Response:*** Concur. The risk management process for the Tethered Satellite System (TSS) continues to focus on hazard analyses and their implications for the Space Shuttle Program. There is an operating strategy that assures all potential satellite control issues will not become hazardous to the Shuttle. A "Safety of Flight" operations envelope is being defined using performance gates that assure Orbiter maneuvers used to avoid contact (breakout techniques) remain viable during all TSS mission phases. The

"Mission Success" operations envelope is contained within the safety of flight envelope so that mission success will not conflict with safety. The performance gates will be reflected in the flight rules and console documentation. The hazard analysis and safety review process along with operations working groups are proceeding at greater levels of detail to continue to implement this strategy.

**APPENDIX C**  
**AEROSPACE SAFETY ADVISORY PANEL ACTIVITIES**  
**FEBRUARY 1991 - JANUARY 1992**

**FEBRUARY**

- 19-22      Aerospace Medicine Advisory Committee Meeting; NASA Headquarters  
26          Space Station Work Package #4 Rocketdyne Briefing; Cleveland

**MARCH**

- 22          ASAP Annual Report to Administrator; NASA Headquarters

**APRIL**

- 30          Intercenter Aircraft Operations Panel Meeting; Cocoa Beach

**MAY**

- 1            Intercenter Aircraft Operations Panel Meeting; Cocoa Beach  
2-3        Intercenter Aircraft Operations Panel; Washington, DC  
9            Space Shuttle Orbiter Autoland; Johnson Space Center  
21          Space Station Program; NASA Headquarters  
22          Space Shuttle Program; NASA Headquarters  
22          Office of Management and Budget; Washington, DC  
28          NASA Safety Reporting Systems; NASA Headquarters

**JUNE**

- 17-19      Aerospace Medicine Advisory Committee Meeting; NASA Headquarters  
19          Space Station Restructure and Space Shuttle Main Engine; Rocketdyne,  
              Canoga Park  
19          ASAP Management Meeting; NASA Headquarters  
20          Space Shuttle Orbiter Autoland; Johnson Space Center

## JUNE (Cont.)

25 National Research Council Panel on Advanced Solid Rocket Motor;  
Washington, DC

## JULY

16-17 Space Shuttle Launch and Landing Processing; Kennedy Space Center

## AUGUST

5 Advanced Solid Rocket Motor; Aerojet, Sacramento

6 Aeronautical Programs and Human Performance; Ames Research Center

6 Space Shuttle Performance; Rockwell, Downey

7 Flight Programs; Dryden Flight Research Facility

9 Space Station Freedom Program, Level I; NASA Headquarters

12-13 Space Station Freedom Program, Level II; Reston

20 Space Shuttle Processing/Operations; Kennedy Space Center

21 Space Shuttle/Space Station Logistics, Kennedy Space Center

21 Advanced Turbopump Development Program; Pratt & Whitney, West Palm  
Beach

## SEPTEMBER

4-5 Redesigned Solid Rocket Motor/Advanced Solid Rocket Motor; Marshall  
Space Flight Center

## OCTOBER

9 Space Station Work Package #4; Lewis Research Center

9-10 Space Shuttle Program Directors Management Review; Johnson Space  
Center

16-17 Manned Space Flight Activities; Johnson Space Center

18 Space Station Integration; Johnson Space Center

**NOVEMBER**

- 6-7 NASA/Contractors Conference; Houston
- 4-6 AIAA 4th Space Logistics Symposium; Cocoa Beach
- 6-8 Integrated Logistics Panel; Kennedy Space Center
- 7 STS-44 Flight Readiness Review; Kennedy Space Center
- 13 Space Station Freedom, Work Package 2; McDonnell Douglas Company; Huntington Beach
- 14 Human Factors, EVA; Ames Research Center

**DECEMBER**

- 4 Tethered Satellite System; NASA Headquarters
- 10-11 Intercenter Aircraft Operations Panel; San Diego



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