

**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.

**NASA Response:** Concur. NASA is continuing to consider alternatives for ensuring safe return of the SSF crew. Current program requirements are that an assured crew return capability is a prerequisite for the Permanent Manned Capability (PMC) phase. Hardware development should also follow a schedule to support the PMC phase. However, funding to support the full development of this capability is not presently budgeted, and approval to start has not yet been granted by Congress.

**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.

**NASA Response:** Concur. Failure Modes and Effects/Hazard Analyses have identified areas of potential risk during assembly. The assembly procedure and hardware will include a cone and feeding guide that provide tolerance for eccentricity in the mating process. The integration contractor is developing programs and test plans for the motorized bolts to check for misalignments that might preclude mating. Assembly process and hardware quality tests are being generated to preclude any obstacles to a successful assembly.

**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.

**NASA Response:** Concur. DMS software development will be monitored closely to ensure that the software is at a satisfactory stage for the DDR.

## 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.

**NASA Response:** Concur. The Space Shuttle Program has baselined a set of loads to account for the increased buffet environment. Additionally, the Space Shuttle Program has implemented a plan to measure loads during missions. Assessments have shown adequate mission life of the body flap for current missions and overall life still is being evaluated. Additionally, the Shuttle Modal Inspection System (SMIS) is being used to track potential damage of 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.

**NASA Response:** Concur. Successful tests have indicated that the SMIS is a reliable method to detect changes in stiffness and dynamic behavior of the Orbiter body flap, elevon, and rotor speed brake (control surfaces). The SMIS is not intended to replace current inspection procedures but is to supplement standard inspection procedures to help detect early damage in areas that cannot be inspected. NASA has not deleted any structural inspection requirements documented in the Operational Maintenance Requirements and Specifications Document (OMRSD).

**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.

**NASA Response:** Concur. NASA has a program in place to train and qualify inspectors to inspect TPS tiles. In addition, quantitative techniques are being investigated to reduce the technique-sensitive characteristics of the current, operator-dependent, inspection techniques.

Currently, all new tile inspections require bond verification testing. Any postflight tile suspect bond conditions also are verified along with conducting engineering "deflection" tests. A dozen certified bond inspectors presently are being used to qualitatively evaluate suspect tile bonds. The individuals have been trained on-the-job and consist of contractor and government engineers. The number of trained personnel will remain the same unless unforeseen increases in bond anomalies occur.

The Kennedy Space Center (KSC) is actively pursuing the development and implementation of an alternative nondestructive evaluation (NDE) method for performing tile bond verification. Presently, a math model of the tile system is being formulated that will be used to evaluate the abilities of NDE systems being developed by two independent contractors. These NDE systems use vibration imaging patterns correlated to bond discrepancies to identify bond anomalies.

**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.

**NASA Response:** The Space Shuttle Program has dedicated Orbiter Maintenance Down Periods (OMDP) at 3-year intervals for the performance of major modifications, structural inspections and other interval inspections. The decision to retain the same organizational structure at the Kennedy Space Center (KSC) for planning and management of both OMDPs as well as turnaround processing is based on the following:

- From a fiscal standpoint, separate organizations are not an affordable option. OMDPs for the fleet of four Orbiters on 3-year intervals do not provide the steady workload to justify a separate organization to manage OMDPs.

- Use of dedicated processing teams for each Orbiter vehicle has resulted in significant "corporate memory" within each vehicle team and a demonstrated capability to accomplish major Orbiter modifications and interval inspections. These processing teams include both NASA and the Space Shuttle processing contractor, as well as Space Shuttle element launch support service contractors.
- Where applicable, Orbiter contractor and vendor teams are utilized for OMDP tasks that require their special skills.
- Because processing management teams are dedicated to each Orbiter, the management of the OMDP presents no impact to the management of normal turnaround processing.

**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.

**NASA Response:** The current autoland system capability is functionally adequate and verified as a backup entry system with some crew participation required. Beginning with STS-53, a two-flight detailed test objective will evaluate autoland performance through wheel stop. Further, a program study is under way to define the necessary hardware, software, human factors, and system analyses required to support an upgraded autoland system for extended duration Space Shuttle flights where this autoland system could be the prime mode for entry operations.

**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.

**NASA Response:** Concur. The Space Shuttle Program has formally baselined the embedded V&V process and established the requirements in NSTS 08271, Flight Software Verification and Validation Requirements; formally established a V&V policy requiring program elements to adhere to this process; and assigned the SR&QA organization as the independent overseer assuring adherence to this process. The Space Shuttle V&V process includes maintenance of detailed test procedures on many levels for the existing test facilities available to the program. Although the program feels very strongly that the embedded V&V process is excellent, the NRC has been requested to evaluate the Space Shuttle's embedded V&V process relative to the need for IV&V. NRC's evaluation is in process with planned completion targeted for September 1992.

Additionally, NASA plans construction of an IV&V facility in Fairmont, WV in 1992. Methods of improving and streamlining the IV&V process will be studied at this facility. Based on criticality and category of the software to be independently validated and verified, the NASA IV&V activity will permit tailoring to specific software project needs. It is not the intent of these independent activities to duplicate all verification and validation (V&V) tests, but to provide support and consistency to enhance the V&V process.

**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.

**NASA Response:** The GPC Error Detection and Correction circuitry cyclically accesses each word in the 256K memory every 1.7 seconds. Because any SEU error is corrected at that rate, there is minimal chance of the memory being "saturated," regardless of the duration of exposure. The same circuitry also generates a count whenever it encounters and corrects such an error, thereby providing corroborating data to compare with the environmental analyses performed to predict SEU rates. The same EDAC architecture is used in the Space Station onboard 386 processors. That processor family also has been selected for the new Space Shuttle Multifunction Electronic Display System (MEDS). It is anticipated that the MEDS will allow future mission-related software growth without directly impacting the flight-critical code in the GPCs. Available usable memory in the GPC appears to be adequate well into the next decade. It is probable that hardware obsolescence will arrive well before practical memory limits are reached. Considerations for GPC upgrades should be initiated in the next 3 to 4 years through the Assured Shuttle Availability (ASA) process.

**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.

**NASA Response:** Concur. As part of the software upgrade process, reviews are held to determine which activities are best shifted from the crew procedures. Astronauts have actively participate in these processes and reviews. Human factors specialists also contribute to this process.

The Space Shuttle Program has and will continue to implement flight software automation of crew procedures that are deemed a significant threat to flight safety or mission success due to the level of difficulty. Tasks for which manual procedures are adequate are judged based on the trade-off of value added/implementation risk against other flight software priorities. During the requirements baselining of the last three Operational Increments (i.e., OI-21, -22, -23), a significant number of software change requests were approved that automated existing crew procedures. Examples include (1) single engine auto contingency abort, which defined the automation of vehicle maneuvers following the failure of two Space Shuttle Main Engines; (2) abort sequencing redesign, which automated some of the crew procedure for aborts; (3) Transatlantic Abort Landing (TAL) droop control, which automated crew procedures to keep the vehicle above a minimum target altitude; and (4) Universal Pointing Future Maneuver-Digital Autopilot (DAP) that significantly reduces the crew procedures for selecting the most appropriate DAP configuration to enter from 14 separate entries to a single entry.

#### **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.

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

**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.

**NASA Response** Concur. As noted, we are continuing to make progress in the Space Shuttle Main Engine (SSME) component reliability and safety program. The main combustion chamber (MCC) wall damage incurred by the two-duct powerhead has been arrested through a combination of hardware and operational changes. A new procedure has been developed for assuring proper liquid oxygen (LOX) post-biasing and a change has been incorporated to the coolant control valve sequence. Also, as noted, the single-tube heat exchanger testing is on scheduled. NASA plans to continue to pursue these activities vigorously within funding constraints.

**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.

**NASA Response:** While LTMCC and enhanced fabrication of the SSME are desirable, they have not been deemed to be essential to continued safe operations of the SSME. Originally, LTMCC was proposed to accommodate sustained SSME operation at the 109 percent power level. The requirement for higher operating power levels than at present has been deferred. The current SSME fabrication techniques and MCC design continue to be safe and reliable for flight. The advantage of LTMCC operation at higher rated power levels with regard to operating speed/pressure/temperature and advanced fabrication with regard to manufacturing and inspection have not been shown to justify the cost of these programs given current NASA budgetary constraints.

**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.

**NASA Response:** The VA-HUD-Independent Agencies FY 1992 Appropriations Act reduced funding for development of the alternate turbopumps by \$40 million, and the conferees reported their belief that the fuel ATP should be terminated. The conferees based this on the successful certification of improvements to the current fuel pumps and on increased development costs.

The original contract for development of the fuel and liquid oxygen (LOX) ATPs was signed in December 1986. The contract cost for development of both fuel and LOX pumps was \$198.2 million. Also, \$50 million was provided for additional hardware and analysis for a total of \$248.2 million.

The original estimate for implementing the Pratt and Whitney pumps into the fleet was essentially "no cost" because this expense would offset the replacement and refurbishment expense that was already included in the budget for Rocketdyne. However, an "after-the-fact-estimate" for implementation of the alternate turbopumps was calculated to be \$160.3 million.

The sum of these estimates (\$248.2 million and \$160.3 million) is \$408.5 million. Assuming the expense of developing and implementing the fuel ATP is one half the estimate, the result is an original cost estimate of \$204.2 million. However, current estimates for development and implementation of the fuel ATP are between \$498 million and \$560 million. This is a 144% to 174% increase over the last 5 years, depending on which figure is used. There is no contract for implementation, therefore, only rough estimates are available. It should also be noted that a significant amount of cost growth was caused by schedule stretchouts and additional pump sets required as the result of technical problems during development.

Since the enactment of the FY 1992 Appropriation Act, NASA has thoroughly reviewed the high-pressure turbopump enhancement program. After careful consideration of a myriad of safety, supportability, cost and budget factors, the Space Shuttle Program recommended, with the Administrator's concurrence, that the alternate fuel turbopump should be deferred -- not terminated -- in order to focus on development of the LOX ATP. If the LOX ATP development is successful and the pump is certified for flight in FY 1994 as planned, the development of the fuel ATP will be restarted that year. This schedule slippage is estimated to increase development costs by \$206 million and implementation costs by \$50 million or a total increase of \$256 million for the fuel ATP.

In responding to the reduced funding, we are not abandoning the investment made in the fuel ATP development program. We continue to believe that the fuel ATP will provide increased flight safety margins and reduce maintenance requirements. However, in this period of scarce resources, we are forced to focus our efforts on first successfully completing development for the LOX ATP which is our most urgent priority. This action follows our careful review of the status for the development, safety, and budget consideration, as well as consultation with program management both in Washington and at the MSFC, NASA's reliability and safety personnel, and with the responsible contractor management.



## **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.

**NASA Response:** Concur. Marshall Space Flight Center (MSFC) currently is evaluating the ASRM O-ring material, as well as several other candidate materials, for possible use in the RSRM program to eliminate the field joint heaters and their installation. The MSFC Material and Processes (M&P) Engineering seal team has samples of the candidate materials and is performing a matrix of performance tests.

**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.

**NASA Response:** Concur. Scale-up of the continuous mix process is being scrutinized closely by both NASA and the contractors. Issues that result from propellant runs at the continuous mix pilot plant are highlighted for correction during a follow-on run. Each issue and its resolution is viewed for its possible relevance in the full-scale facility. Trending of the parameters in the continuous mix pilot plant is being performed to assess data that will be beneficial in the scale-up. Propellant rheology studies of the ASRM propellant formulation are being conducted. Schedules and specific test plans will be prepared for facility checkout and activation. Particular emphasis will continue to be placed upon safety-related issues.

**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.

**NASA Response:** Concur. The human operators' roles in the solid rocket manufacturing process will be clearly defined and documented. Emphasis will be placed on training, the operator interface with the computer system, and the safety aspects of the manufacturing process.

**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.

**NASA Response:** Concur. A number of internal and external groups have reviewed the contents of the ASRM Development and Verification (D&V) Plan including the National Research Council, National Academies of Sciences and Engineering. Many of the group's recommendations already are included in our planning and we have incorporated recommendations as appropriate. NASA will be active participants and monitor program execution as it proceeds through the various sub-scale and full-scale test articles, development and qualification motors, and the pathfinder motor.

**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.

**NASA Response:** Concur. There is a waiver to the aft skirt factor of safety valid only for the RSRM. However, the Space Shuttle Program recently approved a development program for an aft skirt modification with the goal of restoring the factor of safety to 1.4. This development program is scheduled so that it will support both RSRM and ASRM. The current instrument that measures critical skirt strains during launch will remain in place indefinitely to monitor the health of the hardware and establish an extensive engineering data base. Data are reviewed on a flight-by-flight basis by engineering and safety organizations.

**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.

**NASA Response:** Concur. Development of ASRM logistics will continue to include the active participation of NASA and contractor personnel. Both NASA and contractor personnel are members of the Integrated Logistics Panel (ILP). The ASRM Logistics status is presented at each ILP quarterly meeting.

## **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).

**NASA Response:** Concur. While all Orbiter landings have been safe, NASA will continue to focus on improving procedures and training to enhance landing margins. The Space Shuttle Program and the operational elements are determining the necessity of adding additional potential energy to the final flight phase. Two of the parameters currently under evaluation are increasing the approach speed and the outer glide slope angle. These systems are being flight tested in the Shuttle Training Aircraft (STA) and the vertical motion simulator. Improvements in real-time communications to the flight crew of additional environmental and STA performance data has been implemented.

**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.

**NASA Response:** Concur. NASA is committed to a series of new initiatives designed to enhance the hands-on accountability of individuals at the task level and improve processing flow. The Space Shuttle Program has requested all Space Shuttle projects to continue striving for efficiencies in the checkout requirements and the implementing procedures at KSC. The Space Shuttle Program recently completed a project-by-project review of the OMRSD requirements. The goal was to eliminate or reduce "vehicle" checkout requirements that were considered redundant testing or over-testing of a system. This is now beginning to appear in the OMI as efficiencies to operations. A policy that has been put in place by the Space Shuttle Program defers testing of a function until reaching the pad if (1) that function is required to be checked out in an

integrated test and (2) the system/component can be reasonably repaired or removed/replaced at the pad. Process reviews and process analyses by the task teams still are being promoted as another technique to improve processing operations.

**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.

**NASA Response:** Concur.

**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.

**NASA Response:** Concur. NASA is continually reviewing OMI processes and signature requirements to improve content and consolidate paperwork systems and reduce processing time. As part of the continuing effort to improve the quality of OMIs, a Work Preparation Support System (WPSS) function is being implemented as part of the Shuttle Processing Data Management System II (SPDMS II), which will automate both the formatting and parts/materials listings of OMIs. This improvement will reduce the time needed to prepare OMIs by automating portions of the documents that previously were prepared manually. A program change also is being implemented to redefine technical operating procedure signature responsibilities to further enhance processing efficiency. Standard Practice Instructions (SPIs) for Space Shuttle processing are being released, which reduce unnecessary signature requirements in accordance with the approved program change. Memoranda of Understanding between the Space Shuttle processing contractor and Space Shuttle element launch support services (LSS) contractor organizations at KSC have been updated to reflect detailed implementation of these improvements.

**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.

**NASA Response:** Concur. The task team approach to accomplish processing flow tasks safely, correctly, and on schedule has been implemented utilizing a pilot program approach within the Orbiter Processing Facility (OPF). With the success of the OPF operation fully recognized, other operations (solid rocket booster stacking, external tank, and Orbiter mating) will implement the task team approach. One improvement presently being assessed is the transfer of responsibility for the task team leader to the individual line manager to enhance coordination with the technician, Safety, Reliability, and Quality Assurance (SR&QA), etc. An updated standard practice instruction (SPI) has been prepared to include other operational areas and a new schedule for implementation is in work.

**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.

**NASA Response:** Concur. A joint KSC/JSC problem process improvement team chartered by the Space Shuttle Program (SSP) has been formed to analyze the Orbiter discrepant hardware/logistic processing flow. The sequence of events presently required to process discrepant hardware is undergoing assessment to determine how best to streamline and make the system more responsive. Recommended changes are scheduled for presentation to the SSP in mid-1992. In addition, the Space Shuttle Critical Process Improvement Team has completed a review of the current NASA management/contractor interface relationships for logistics for all Space Shuttle elements. A report identifying issues and corrective actions has been submitted to the Space Shuttle Program.

**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.

**NASA Response:** Concur. SPDMS II is being implemented as an evolutionary, augmented replacement for existing data management capabilities. Project teams for the four major functional projects, as identified in the Tactical Plan dated August 19, 1991, have been formed. Each team is composed of contractor and NASA users, project office personnel, and software developers, and is managed by the primary user of that function. These teams have been in place since December 1991. All existing applications have

been mapped to a functional project to assure that continuity exists between these applications and new activities. Existing applications will be incorporated into or replaced by these new activities. Management of this process by user led project teams will ensure that SPDMS II provides the same or improved functionality when completed.

## **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.

**NASA Response:** NASA agrees and realizes that the importance of the Space Shuttle Program management's emphasis on all Space Shuttle Program assets is essential to continued economic operations and safety of flight. Space Shuttle Program management will continue to review all program assets distributions to assure proper levels of support are available for the NASA fleet.

**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.

**NASA Response:** NASA agrees that the ILP is a good coordination medium that facilitates the centralization of NASA Centers with their contractors for review and reporting on their logistics activity.

**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.

**NASA Response:** Concur. This is an area of regular management review. Each logistics management responsibility transfer (LMRT) recommendation is brought forward for the Space Shuttle Program Director's approval after thorough scrutiny by the project elements responsible for the hardware. Hardware, consumables, and expendables that are sufficiently mature in design are the only items considered for transfer to KSC.

**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.

**NASA Response:** Concur. This is an area that is reviewed by Space Shuttle Program management annually through the POP budget reviews. The NASA Shuttle Logistics Depot (NSLD) is expected to continue its growth as the Space Shuttle Program continues to mature and vendors change.

**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.

**NASA Response:** Concur. NASA continues to review each cannibalization by screening all inventory systems for availability prior to formal recommendation and presentation for approval of cannibalization by the Space Shuttle Program Director. As the Space Shuttle flight rate changes, the inventory levels are adjusted to meet Space Shuttle Program's requirements.

**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.

**NASA Response:** Concur. This is an area of high visibility within the Space Shuttle Program management. Each project element reviews their repair turnaround time (RTAT) on a daily basis and reports to management as required. Workload coordination, schedules, and needs of each contractor (repair agency) are reviewed monthly and adjusted as their requirements are clarified.

**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.

**NASA Response:** Concur. Since the delivery of Endeavour (OV-105), the below-minimum balances have increased. This was part of the plan to expedite the delivery of this vehicle. The established stocking levels will improve regularly as OV-105 hardware is delivered. This will be monitored by Space Shuttle Program management to assure availability of hardware necessary to meet the current flight rate.

**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.

**NASA Response:** Concur. There is a continuous effort by Space Shuttle Program management within each project element to determine vendors and/or OEMs that are projected for discontinuing production of Space Shuttle items. As these production losses are identified, NASA is taking steps through the Assured Shuttle Availability (ASA) processes to qualify alternate vendors and, where feasible, certify the NASA Shuttle Logistics Depot (NSLD) to perform the required maintenance and repair. The Space Shuttle Program is developing a Parts Availability/Obsolescence Trend System (PATS) to identify potential and actual problems.

The KSC Director of Shuttle Logistics has developed a list of critical items that could adversely impact Shuttle Logistics support. These items are being purchased on a priority basis to avoid potential shortages.



## 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.

**NASA Response:** Concur. In addition to publishing the NMI in August 1991, NASA also developed two aircraft management operations handbooks that provide further detail on aviation safety requirements. These handbooks have been approved and distributed. Also, a revised Basic Safety Manual (NHB 1700.1) is in final review prior to publication. Chapter 7 addresses aviation safety. The Aircraft Management Office has been elevated to report directly to the Associate Administrator for Management Systems and Facilities, and is responsible for coordinating flight policies throughout NASA. General J. Timothy Boddie has been appointed to head this office.

**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.

**NASA Response:** Concur. NASA will continue its historical role in aeronautical flight research. Improved procedures will be incorporated at every opportunity and lessons learned will be implemented NASA-wide. Safety remains the most important principle in our aeronautical flight research programs.

## 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.

**NASA Response:** Concur. NASA has an ongoing effort to better understand crew rest cycles and circadian rhythm shifting in support of the Space Shuttle and Space Station operations. Plans for acquiring and evaluating additional flight data will be developed and implemented. In early 1990, NASA began a circadian cycle shift project to investigate the issue of crew sleep quantity and quality from the crew perspective. This project entailed meetings with government and academic experts in the areas of sleep and circadian cycles, including NASA aircrew researchers, who examined existing Space Shuttle flight procedures and developed recommendations for improvements. These efforts were supported by mission tests of improved methods for effecting preflight sleep and circadian shifting required to ensure crewmember alertness during critical flight periods. The same techniques were applied to dual shift mission crews for the purpose of shifting the "night team" to mission sleep times prior to launch. Sleep and circadian cycles were effectively shifted and the techniques were well received by the crewmembers. Preflight sleep and circadian shifting procedures have been a part of routine Space Shuttle crew readiness preparations over the last 2 years and will continue through the Space Station era.

**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.

**NASA Response:** Concur. NASA currently sponsors a pilot project at the Kennedy Space Center to determine the value to the safety program of incorporating human factors principles. This project focuses primarily on facility design and acquisition. The Space Station Processing Facility has been selected to serve as a demonstration vehicle.

Draft guidelines have been developed and are being tested in the pilot project prior to publication and NASA-wide implementation.

**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.

**NASA Response:** Concur with intent. NASA encourages open communication, employee interaction, and the development of attitudes of personal responsibility for work performed through application of Total Quality Management techniques. However, we do not see a need to adopt the FAA system which applies to multiple airlines in multiple locations. For the number of aircraft and limited locations NASA has, our current reporting systems combined with personal responsibility have been effective.

**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.

**NASA Response:** It is highly unlikely that this additional audit would result in any new significant information. An examination of available data and processes indicates that both the combined MSFC and Headquarters review of the TSS quality system collectively represent adequate reviews. MSFC reviews, which were the source of identification of the materials problems, have been thorough. The TSS Quality Assurance Program has undertaken several audits in the period 1986 through 1991 including two safety critical structure audits, one of which resulted in identification of the condition A 15-5 PH material and configuration inspections. A special audit was conducted in November 1991 to address contractor materials and procurement procedures attendant to situations identified with the vernier motor clutch and 15-5 PH steel. The quality systems that were considered to be prime contributors to the materials

procurement issues have been reviewed. Steps have been taken to ensure that implementation of the recommended procedures in the quality systems are performed correctly by all personnel concerned.

There is no flight safety issue and all problems identified by the above, existing quality systems have been resolved to the satisfaction of the senior NASA management. Code Q will continue to periodically review the quality systems to ensure that their capabilities are maintained at required levels.

**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.

**NASA Response:** In the near term, through the initial assembly of the Space Station Freedom, the existing Space Shuttle suit is capable of safely meeting all known operational requirements. Specification and development of a new suit and EMU will be undertaken as requirements become better defined and funding becomes available. NASA rejects this recommendation per the following rationale. First, over 10 years of astronaut EVA training for HST and Space Station assembly missions has not revealed any operational, design, or safety problems related to performing any necessary EVA using the existing Space Shuttle EMU system. The Space Shuttle EMU works well and is a proven safe system. Second, the AX-5 and Mark 3 systems must be recognized for exactly what they are. They were strictly R&D programs and neither prototype suit was intended to be flight capable. Indeed, many additional years effort would be required to turn these designs into flight systems. AX-5 and Mark 3 have served well as proving grounds for new suit concepts; in fact, several unique design features have been identified that are under review for potential future incorporation into the existing Space Shuttle EMU.

**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.

**NASA Response:** Concur. Current prebreathe protocols are based on data from more than 1200 altitude chamber runs and space flight EVA experiences gathered over the last 15 years. NASA has in place ongoing bends risk assessment research activities performing continuous updates to this data based on manned vacuum chamber tests, EVA training events and on-orbit EVA activities. In addition, a program is in work to develop a portable bubble detector for use during on-orbit EVA activities to characterize zero gravity effects on bends risk.

NASA has dedicated a significant amount of research and development to exploring the physiological effects of the partial atmospheres experienced during space flight EVA activity. NASA will continue to research the health effects of EVA activity as a function of length and intensity, both of which are strictly controlled. This research includes crew health monitoring during Space Shuttle missions and basic life science experiments conducted at NASA research centers.



**APPENDIX C**  
**AEROSPACE SAFETY ADVISORY PANEL ACTIVITIES**  
**JANUARY 1992 - JANUARY 1993**

**JANUARY**

- 28    Advanced Solid Rocket Motor Software, Iuka, MS
- 30-31 Automation Science Research Facility, Ames Research Center

**FEBRUARY**

- 18-19 Space Shuttle Orbiter Autoland, Ames Research Center
- 18-19 Aerospace Medicine Advisory Committee, NASA Headquarters
- 27    Space Shuttle Orbiter Autoland, Rockwell, Downey, CA

**MARCH**

- 9-14   Integrated Logistics Panel, Thiokol, Brigham City, UT
- 10    HL 20 Program, Langley Research Center
- 17    Aerospace Safety Advisory Panel Annual Report to NASA Administrator and Congressional Staff, Washington, DC

**APRIL**

- 2    Assured Crew Return Vehicle, Johnson Space Center
- 22    Redesign Solid Rocket Motor, Thiokol, Brigham, UT
- 22    STS-49 Flight Readiness Review, Kennedy Space Center
- 29    Aerospace Safety Advisory Panel Activities Discussion with Acting Deputy Administrator, NASA Headquarters

## MAY

- 12-13 Space Station and Panel Update with Administrator, NASA Headquarters
- 16 STS-49 Endeavor Landing, Dryden Flight Research Facility
- 18-20 Safety, Reliability, Maintainability and Quality Assurance Discussions with Programs Assurance Director, NASA Headquarters
- 20 Auxiliary Power Unit, Sundstrand, Rockford, IL
- 21 Assured Crew Return Vehicle, Johnson Space Center
- 27 Safety, Reliability, Maintainability and Quality Assurance Discussions, Lewis Research Center
- 27 Safety, Reliability, Maintainability and Quality Assurance Discussions with NASA Headquarters Officials

## JUNE

- 2-3 Redesigned Solid Rocket Motor/Advanced Solid Rocket Motor, Marshall Space Flight Center
- 5 Safety, Reliability, Maintainability and Quality Assurance Discussions, NASA Headquarters
- 16-17 Intercenter Aircraft Operations Panel, NASA Headquarters
- 22-24 Aerospace Medical Advisory Committee, NASA Headquarters

## JULY

- 6-7 Safety, Reliability, Maintainability and Quality Assurance Discussions, NASA Headquarters
- 14 Space Shuttle Main Engine; Advanced Solid Rocket Motor; National Launch System; National Aerospace Plane Program; Test Technology; Center Overview, Stennis Space Center
- 15 Simplified Aid for EVA Rescue (SAFER) and Mission Control Center, Johnson Space Center
- 16 Autoland Demonstration, White Sands

- 20-24 Space Shuttle Main Engine Assessment Team, Rocketdyne, Canoga Park, CA
- 28 Safety, Reliability, Maintainability and Quality Assurance Discussions with Associate Administrator for Safety and Mission Quality, NASA Headquarters
- 29 Space Shuttle Enhancements with Associate Administrator for Space Flight, NASA Headquarters
- 29 Aircraft Operations with Director, Aircraft Operations, NASA Headquarters

### **AUGUST**

- 5-6 Space Shuttle Main Engine Assessment, Marshall Space Flight Center
- 18-21 Intercenter Aircraft Operations Panel, Johnson Space Flight Center
- 18 Flight Research Programs, Dryden Flight Research Center
- 20 Space Suits, Space Shuttle Autoland Simulation Demonstration and Human Factors, Ames Research Center
- 24-28 Integrated Logistics Panel, Kennedy Space Center

### **SEPTEMBER**

- 1 Aerospace Safety Advisory Panel Update to NASA Administrator and Deputy Administrator, NASA Headquarters
- 2 Space Council, Crystal City, VA
- 15-17 Space Shuttle Processing and Operations, Kennedy Space Center
- 15-17 Advanced Technology Advisory Committee, Johnson Space Center
- 29-30 Space Shuttle Main Engine Assessment, Rocketdyne, Canoga Park, CA

### **OCTOBER**

- 1-2 Space Shuttle Main Engine Assessment, Rocketdyne, Canoga Park, CA
- 8 Space Station Freedom Work Package 2, McDonnell Douglas Company, Huntington Beach, CA
- 9 Space Shuttle Orbiter, Rockwell, Downey, CA



- 19-20 Aerospace Medicine Advisory Committee, NASA Headquarters
- 26-28 Space Shuttle and Space Station Programs, Johnson Space Center
- 27 Autoland Update with Acting Deputy Administrator, Johnson Space Center

**NOVEMBER**

- 4-5 Space Shuttle Main Engine Assessment Team, Rocketdyne, Canoga Park, CA
- 10 Aerospace Safety Advisory Panel Activities Update to NASA Administrator and Associate Administrator for Safety and Mission Quality, NASA Headquarters
- 16-19 Intercenter Aircraft Operations Panel, Seattle, WA

**DECEMBER**

- 34 Space Shuttle Main Engine Assessment Team, NASA Headquarters
- 7-8 Kennedy Space Center Training Program, Kennedy Space Center
- 15 Space Shuttle Autoland, NASA Administrator, NASA Headquarters

**JANUARY**

- 15 Space Shuttle Main Engine Assessment Team Report to Center and Contractors, Marshall Space Flight Center
- 27 Space Shuttle Main Engine Assessment Team Report to NASA Administrator, NASA Headquarters

**APPENDIX D**  
**ASSESSMENT OF THE JUSTIFICATION AND MISSION**  
**REQUIREMENTS FOR AN ASSURED CREW RETURN VEHICLE**



National Aeronautics and  
Space Administration

Washington, D.C.  
20546

Reply to Attn of: Q-1

July 2, 1992

Honorable Daniel S. Goldin  
Administrator  
NASA Headquarters  
Washington, D.C. 20546

Dear Mr. Goldin:

The Aerospace Safety Advisory Panel (ASAP) is pleased to submit to you the report of its working group, co-chaired by Mr. Richard D. Blomberg and Dr. Seymour C. Himmel, on the Assured Crew Return Vehicle (ACRV) for the Space Station Freedom. This report has been reviewed by the entire Panel membership and reflects its consensus that a single-purpose ACRV is justified and the mission requirements developed by the ACRV Project are realistic and appropriate as a basis for ACRV system requirements.

The working group appreciates the cooperation given it by the ACRV Project Office and the Space Station Freedom Program in the performance of this assessment.

Representatives of the ASAP working group would be pleased to meet with you if you have any questions concerning this report.

Very truly yours,

Norman R. Parmet  
Chairman, Aerospace  
Safety Advisory Panel

## EXECUTIVE SUMMARY

The NASA Administrator requested that the Aerospace Safety Advisory Panel conduct an independent review of the justification and mission requirements for an Assured Crew Return Vehicle (ACRV) for the Space Station Freedom (SSF). A working group of the Panel was established to conduct the assessment. This group reviewed applicable documents and met with the ACRV Project Office staff and its two study contractors. The Panel was gratified to observe that the Project has adopted as its governing philosophy that the ACRV system should satisfy the objective of being Simple, Affordable, Reliable and Available which it embodies in the acronym SARA.

A review of the histories of vehicle systems and installations that operate under conditions analogous to SSF (e.g., submarines, naval surface vessels, other manned space flights and remote bases such as those in Antarctica) indicates that there are three types of circumstances that require emergency evacuation of some or all of their personnel. These are: 1) a medical emergency; 2) an accident which renders the installation uninhabitable; and 3) inability to resupply the installation. Data from the experiences of such analogous systems indicate that the frequencies of occurrence of emergency events such as those noted above are sufficiently high to justify the need for providing a "lifeboat" capability for SSF.

The ACRV Project Office has let contracts for definition and preliminary design of such a "lifeboat" system. Based on the set of emergencies noted above, the Project Office developed three Design Reference Missions (DRMs) and their attendant constraints to guide the contractors' efforts. The DRMs, which parallel the set of emergencies, are described in a set of formal documents providing: performance (functional) requirements, rationales for the requirements, operations concept and a data book. The Panel finds that the DRMs are sound in their content and, aided by the supporting documents, provide excellent definition of the ACRV system requirements. The Panel notes, however, that there is a probability that DRM-1, medical emergency, may co-exist with DRM-2, SSF system accident requiring immediate evacuation, and suggests that this overlap be examined to determine its effects on the design of the ACRV system.

An open issue, currently being studied by the ACRV Project, is whether the landing sites should be on land, on water or both. An important factor is whether the available Search and Rescue (SAR) forces can meet the time lines required for the medical emergency of DRM-1. It would appear that the ACRV must be designed for a return to land while preserving the capability of a water landing.

The Panel concludes that development of an ACRV system is justified, and the defined mission requirements are appropriate. To provide the maximum assurance of crew safety, the ACRV must be available and operable when needed. The Project Office has established an availability of 0.997 as the goal for the ACRV system. An analysis shows that, with hardware of reasonably obtainable reliability yielding an individual craft availability of 0.950, the ACRV system must comprise two vehicles each with full crew capacity in order to meet this system availability goal.

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## 1.0 INTRODUCTION

NASA has always provided the capability for the safe return of astronauts continuously throughout space missions. For Mercury, Gemini, Apollo and Space Shuttle missions, the return capability was inherent because the crew stayed with the reentry vehicle. During the Skylab Program, the Apollo capsule remained docked with the orbiting laboratory to provide a return capability on demand.

The Space Station Freedom (SSF) presents a new challenge for maintaining a continuous crew return capability. The orbiting station is designed to be self sufficient for extended periods of time between visits by the Space Shuttle. When the Shuttle is not docked with SSF, no crew return capability is present unless a separate reentry vehicle or "lifeboat" is provided. This vehicle, although not yet fully defined, has come to be known as an Assured Crew Return Vehicle (ACRV).

In February 1992, former NASA Administrator, Richard H. Truly, in a letter to Mr. Norman R. Parmet, chairman of the Aerospace Safety Advisory Panel (ASAP), requested that the Panel *independently review the justification and mission requirements for an ACRV*. This request was reaffirmed by the present NASA Administrator, Daniel S. Goldin, during a meeting with Mr. Parmet in May 1992. In response, a working group of ASAP members and consultants was formed to examine the ACRV justification, mission requirements and resulting system performance requirements to determine if they justify the inclusion of an ACRV in the SSF design. This working group gathered information from the ACRV Project Office, SSF Program and Project personnel and the two contractors (Lockheed and Rockwell) who are presently involved in ACRV preliminary design. This report presents the findings and recommendations of that working group.

This report focuses on the justification for an ACRV and an assessment of the mission requirements which have been proposed for it. Observations are included on the system performance requirements which have been developed in response to those mission needs. No attempt was made as part of this study to examine systematically specific design or configuration alternatives. Meetings with the two competing contractors were held only to determine the extent to which the mission requirements and *functional* performance specifications were realistic and supportive of the need for an ACRV.

## 2.0 JUSTIFICATION

Several generic options have been proposed to provide the SSF with an assured crew return capability. These range from a dedicated, single purpose vehicle docked with the SSF to a "launch on demand" ground-based Shuttle to rescue crew members. NASA has established an ACRV Project Office at the Johnson Space Center (JSC) to examine alternatives and manage any resulting ACRV definition and development efforts. As part of its work, the ACRV Project examined a range of possible contingencies which might require the availability and use of an ACRV. If one or more of these circumstances were sufficiently likely to occur and could lead to loss of life among the crew, the deployment of an ACRV would be justified.

After enumerating various theoretical possibilities, the ACRV Project examined analogous situations from space flight and earth-bound activities to help assess their likelihood of occurrence and potential severity. It was determined that three situations could arise which would require the on-orbit presence of a return capability. These were a medical emergency due to illness or injury to a crew member, an emergency which renders the Space Station uninhabitable and the

unavailability of the Space Shuttle, which is the only ground based vehicle capable of reaching the SSF and transporting its crew. Each of these contingencies was deemed credible and was expected to occur multiple times over the 30 year operational life of the Space Station.

Since scenarios were identified which supported the need for an ACRV, the Project concluded that its development was justified. It then proceeded to define the specific mission requirements that an ACRV design would have to meet.

### **3.0 MISSION REQUIREMENTS**

In order to guide the development of an ACRV, the Project Office translated the three contingencies it identified as justifying an ACRV into specific design reference missions (DRMs). These are:

- **DRM-1** - Return of an ill or injured crew member for treatment on the ground
- **DRM-2** - Total evacuation of the SSF in the event that it becomes uninhabitable due to events such as a fire, toxic spill or loss of life support capability
- **DRM-3** - Return of the entire crew if the Space Shuttle becomes unavailable.

Each of these design reference missions is supported by analyses of the probability of their occurrence over the planned 30 year lifetime of the Space Station Freedom.

#### **3.1 DRM-1: Medical Evacuation**

The possible need for a medical evacuation was assessed by the ACRV Project through an examination of analogous populations including U.S. and Soviet space flight, U.S. Navy seaborne experience and long duration Antarctic expeditions. The estimated need for medical evacuations of Space Station varies somewhat depending on which analog population is used. The ACRV Project has adopted a rate of seven medical evacuations over the 30 year SSF life for planning purposes. This rate appears to be well justifiable from the available data. Even if this rate is overstated by a considerable amount, there appears to be an extremely high likelihood that multiple medical evacuations will be needed over a 30 year SSF life.

As presently conceived, DRM-1 requires that an ill or injured crew member reach a critical care facility on the ground within 24 hours of the time that the injured person is stabilized and declared ready for transport. This 24 hour timeline allows for the possibility of significant on-orbit loiter time so that the landing can be targeted for a preferential landing site. The timeline provides for a maximum of three hours between the time of landing and the arrival of the patient at a critical care facility (up to one hour for removal and two hours for transport). This latter requirement likely represents a significant challenge for a water landing situation.

The 24 hour timeline has been developed with extensive inputs from the medical community. This is the *maximum allowable* time that is considered to be consistent with the basic objective of restoring the injured or ill crew member to a healthy state. It is acknowledged, however, that a more timely arrival at the care facility would be preferred if its achievement did not compromise some of

the other parameters associated with DRM-1 such as impact G-loads. It therefore might be better to express the DRM-1 requirements in terms of reaching an appropriate care facility for the illness or injury in question as soon as possible after stabilization but in no event later than 24 hours.

Finally, DRM-1 does not inherently require that all crew members be evacuated from the SSF. It is assumed that the "patient" will be accompanied by at least one and perhaps two other crew members to operate the ACRV and/or render emergency medical care during the reentry. The assumption is that the Space Station can accommodate the balance of the crew if they elect to stay and such a reduced crew complement is permitted by mission rules. These rules will likely include the necessity of having an available ACRV of acceptable reliability with a capacity sufficient to return the remaining crew.

### **3.2 DRM-2: Space Station Emergency Evacuation**

DRM-2 covers a situation in which the entire crew must be evacuated from the Space Station due to an emergency resulting from system failures, meteoroid or debris impacts or other threats (fire, collision, accident, toxic spill, etc.) which render the Station temporarily or permanently uninhabitable. Detailed estimates of the probabilities of these various events are underway or contemplated as more data become available. Current preliminary Project estimates range from the need for 4.3 evacuations in 30 years based on U.S. manned space flight experience to 6 evacuations in 30 years if U.S. Navy submarine abort surfacing data are considered. The ACRV Project is using the lower estimate for its planning purposes. This may be somewhat of an understatement of the real frequency of DRM-2 occurrence because the analyses reviewed by the ASAP would appear to underestimate the probability of inadvertent crew operations during 30 years of operations by multiple crews.

The DRM-2 scenario calls for the capability of a complete evacuation and separation of the ACRV from the SSF within three minutes of the beginning of the crew's ingress to the ACRV. This rapid departure is considered necessary to protect the crew from the effects of any emergency which prompted the evacuation.

### **3.3 DRM-3: Shuttle Unavailable**

The ACRV Project has realistically addressed the possibility that the Space Shuttle will become unavailable as a means of transporting a healthy crew back to earth at the end of its normal duty time on Space Station. The Shuttle could become unavailable due to a problem with the vehicle itself (e.g., another accident) or as a result of losing a critical support facility such as the Mission Control Center (MCC), Vehicle Assembly Building (VAB) or both launching pads. Natural disasters such as hurricanes, accidents and hostile acts could each lead to a Shuttle system which was unavailable to retrieve a crew from the Space Station.

Currently, there are no detailed estimates of the probability of occurrence of the various scenarios which could lead to DRM-3. The ACRV Project has examined various ways of estimating the potential loss of Shuttle availability over a 30 year period. These include the failure estimates prepared specifically for the Galileo mission and the demonstrated failure rate based on the loss of the 51-L mission and the actual number of flights actually completed. This has led the Program to consider a range of between three and eight required ACRV missions over 30 years to compensate for Shuttle unavailability.



#### **4.0 SYSTEM PERFORMANCE REQUIREMENTS**

As part of the assessment of the need for an ACRV, the system performance requirements were examined to obtain additional insights into mission requirements and to ascertain if the functional definition of the system was consistent with the design reference missions.

The functional requirements for the ACRV system are contained in the *System Performance Requirements Document (SPRD)* prepared by the ACRV Project Office. This document is an excellent example of well defined *functional* requirements which clearly flow down from the design reference missions but do not presuppose a design solution. The ACRV Project is to be complimented on the excellent requirements analyses and documentation it has provided as well as its overall design philosophy. This philosophy is promoted through the acronym, SARA, which the program has adopted as a reminder that the design should be simple, available, reliable and affordable. It is also noteworthy that the ACRV Project has encompassed all phases of a potential ACRV mission from prelaunch operations through launch, rendezvous and SSF attachment, attached operations, flight and landing to recovery and post recovery. This should help ensure a realistic program development with adequate consideration of life cycle costs.

The ACRV performance requirements are predicated on a design assumption of minimal crew intervention for separation from the Space Station, targeting, reentry and recovery. The crew is considered able to initiate actions and, perhaps, intervene to stop an automatic sequence but is not expected to take an active role in ACRV guidance or system reconfiguration. This appears to be a totally reasonable and necessary view of crew capability since the crew complement, health state and extent of deconditioning are unknowns for any particular ACRV mission. The design reference missions and 30 year projected life of SSF provide further support for a set of requirements which do not rely on human piloting and systems skills. The analogy used by the ACRV Project of the crew entering an elevator and pushing the "down" button seems particularly apt for the defined mission environment.

#### **5.0 CONCLUSIONS AND RECOMMENDATIONS**

The review by the ASAP working group has led to conclusions and recommendations with respect to the justification for an ACRV and its deployment configuration. In addition, observations related to several areas of system performance requirements were developed.

##### **5.1 Justification and Mission Requirements**

It is the opinion of the ASAP that the three basic contingencies used by the ACRV Project to justify the need for an ACRV are credible and do, in fact, support a Space Station requirement for an on-orbit crew return vehicle. Further, the design reference missions arising from the basic contingencies individually and collectively justify the deployment of an ACRV with the Space Station. The probability of occurrence for each of the DRMs is sufficiently high to warrant providing a simple, reliable way to return the crew safely to earth without relying on the Space Shuttle. Further, the potentially fatal consequences of *not* having an ACRV given the almost certain need for it during the 30 year operational life of the Space Station are totally unacceptable risks when the provision of a simple "lifeboat" system can virtually ensure their avoidance. There is nothing inherent in the

design or operation of the SSF which should alter NASA's longstanding policy of providing a continuous "way home" for the astronauts.

Although the three DRMs cover the obvious contingencies, it is believed that the simultaneous occurrence of DRM-1 and DRM-2 is also quite probable. Simply, it is considered likely that many of the emergencies which will result in the need for a rapid, DRM-2 evacuation will also involve one or more injured crew members. This overlap has significant implications for the functional requirements of the ACRV in such areas as its on-board medical systems, ingress capability for injured crew members and mission timelines. It is recommended that the implications of simultaneous DRM-1 and DRM-2 scenarios be given more attention as the requirements are further refined.

## 5.2 Number and Capacity Needed

In addition to justifying the existence of an ACRV, the design reference missions together with the performance requirements for reliability and availability lead to a strong conclusion concerning the number of ACRVs which must be stationed on-orbit and the capacity of each ACRV. Regardless of whether the SSF's permanently manned configuration (PMC) ultimately involves a crew of four or eight astronauts, only three "generic" on-orbit deployment configurations appear possible. This is because the SSF design provides docking ports for a maximum of two ACRVs when it reaches PMC. These three deployment configurations are:

- A single ACRV with the capacity to transport the entire crew complement
- Two ACRVs each of which can transport at least half of the crew but less than the full crew
- Two ACRVs each of which is capable of accommodating the entire crew.

A single ACRV with less than a total crew capacity is precluded by both DRM-2 and DRM-3 which require a total Station evacuation.

At present, the system performance requirements provide for an ACRV system operational availability ( $A_o$ ) of 0.997.  $A_o$  for a single ACRV is simply its own operational availability. For a two vehicle system each of which has less than a full crew capacity,  $A_o$  is the product of the individual vehicle's operational availabilities. Since these vehicles would likely be identical, this would be the square of a single vehicle's  $A_o$ . The operational availability for a deployment of two identical vehicles each with full crew capacity is one minus the square of the *unavailability* of an individual vehicle. When  $A_o$  is calculated for any deployment of two ACRVs, it assumes that the crew always has the capability to reach both ACRVs with equivalent safety. This may not be the case, particularly for DRM-2. However, examining availability using this assumption is a reasonable simplification.

When these formulas are applied to the three generic deployment configurations, an interesting pattern emerges as indicated in the table on the next page which shows system  $A_o$  as a function of individual vehicle  $A_o$ . It can be seen from this table that the single full crew vehicle must itself have an  $A_o$  of 0.997 to meet the present criterion while the configuration with two full crew ACRVs can achieve a system  $A_o$  greater than 0.997 with an individual vehicle  $A_o$  of only 0.950, a

much more realistically achievable reliability. Further, two ACRVs of less than full crew capacity cannot meet the performance criterion even if the individual vehicle  $A_o$  is, itself, 0.997. In fact, this configuration would require an individual vehicle  $A_o$  in excess of 0.998 to meet a system  $A_o$  criterion of 0.997.

$A_o$ of Single ACRV Vehicle	$A_o$ by Deployment Configuration		
	Single ACRV Full Crew Size	2 ACRVs Each < Full Crew	2 ACRVs Each $\geq$ Full Crew
0.800	0.800	0.640	0.9600
0.850	0.850	0.723	0.9775
0.900	0.900	0.810	0.9900
0.950	0.950	0.903	0.9975
0.960	0.960	0.922	0.9984
0.970	0.970	0.941	0.9991
0.980	0.980	0.960	0.9996
0.990	0.990	0.980	0.9999
0.995	0.995	0.990	0.9999
0.997	0.997	0.994	0.9999

Given the foregoing considerations, it is concluded that safely completing the design reference missions can only be realistically accomplished by placing two ACRVs on the Space Station each of which has the capacity to transport the full crew complement. This conclusion is considered independent of any acceptable specification for *system* operational availability. Since there are current plans to accommodate a crew of eight in the final Space Station configuration, this would imply that the deployed ACRV system should be composed of two eight person vehicles attached to the SSF plus at least one assembled and flight-qualified spare to ensure that an ACRV, once utilized, can be replaced in a reasonable period of time without the necessity of maintaining a rapid refurbishment capability.

### 5.3 Observations

As part of the system performance requirements review, several points were raised by the ASAP working group members as worthy of additional consideration. As mentioned above, these were not the result of an in-depth requirements analysis but were simply consensus impressions based on the particular information which was briefed to the Panel. Specific points which it is recommended that the program consider are:

- **Land versus water landing** - The present requirements are not firm with respect to the capability of the ACRV to land on water, land or both. Given the compressed

time requirements for locating, extricating and transporting an injured crew member imposed by DRM-1, it would appear that the ACRV must be capable of a land landing. The significantly greater availability of water landing sites, however, suggests that the system should *also* be capable of a safe water landing.

- **ELV Launch** - The present requirements provide that the ACRV be designed to a "generic" expendable launch vehicle (ELV) environment to retain the option of an ELV launch if this capability is added to the SSF in the future. It would appear prudent to provide for a specific *existing* ELV launch capability as early as possible to reduce the logistics load on the Shuttle and ensure the inherent design compatibility of the ACRV and the ELV.
- **Reusability** - The generic concept of reusability is inherent in the system performance design requirements. Reuse or refurbishment is encompassed by the requirements. While it does appear logical that many high value items can and should be reused, the ultimate decision concerning reusability should await a final design solution. Moreover, it is important that any decision to provide for refurbishment be made on the basis of a detailed cost benefit analysis which includes appropriate consideration of the cost of establishing and maintaining the refurbishment and component manufacturing infrastructures for 30 years.

For further information  
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