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

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

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

Single-Crystal Turbine Blades

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

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

Alternate Turbopump Development Program

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

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

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

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

<u>Redesigned Solid Rocket Motor and Solid Rocket Booster</u>

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

Booster Aft Skirt

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

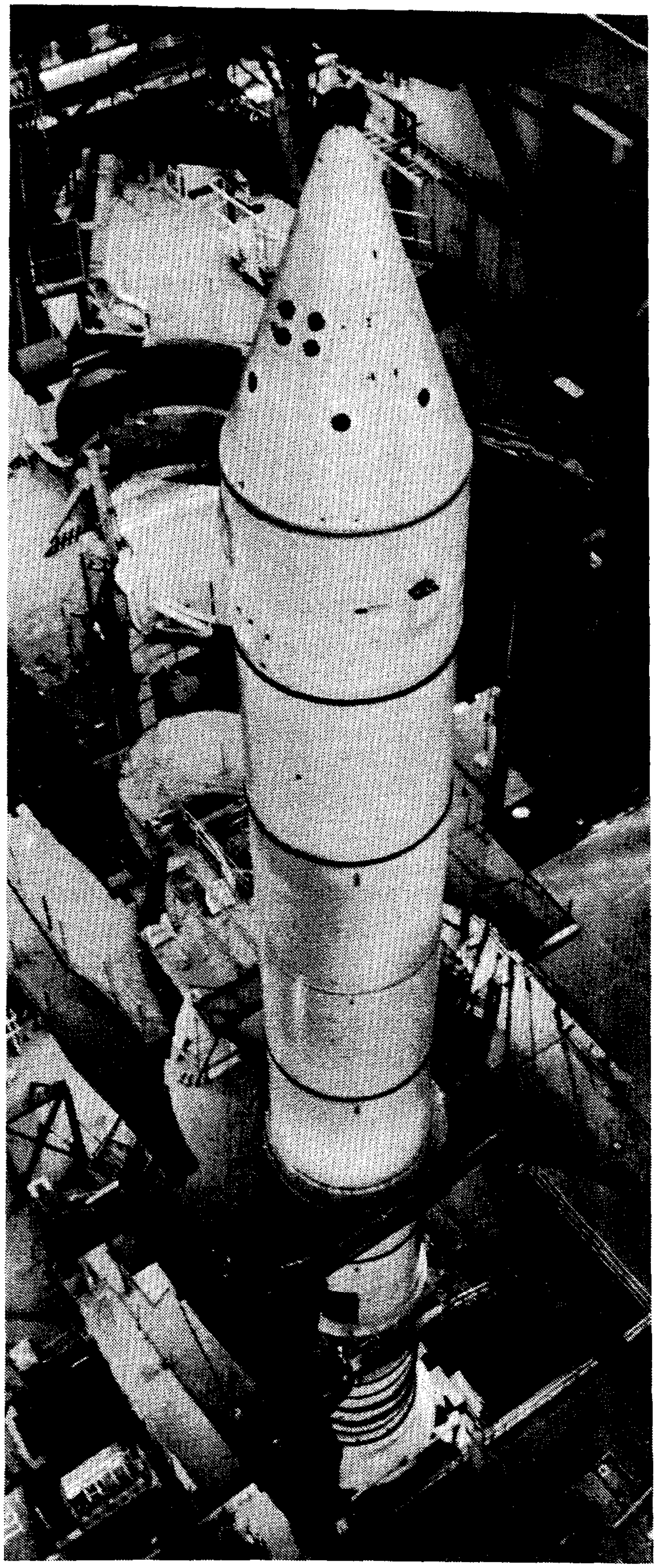
The aft skirt is subject to its maximum loading prior to lift-off during the deflection of the stack ("twang") caused by the start of the three main engines. Main engine thrust buildup and vehicle weight constitute approximately 92 percent of the design load applied to the aft skirt. Therefore, the probability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

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

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

Redesigned Solid Rocket Motor Field Joints

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



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

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

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

Other Considerations

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

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

Advanced Solid Rocket Motor
(Ref: Finding #19)

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

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

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

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

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

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

- Welding of the maraging steel (HP 9-430) of the large diameter case is difficult and can produce voids and cracks in the weldment.

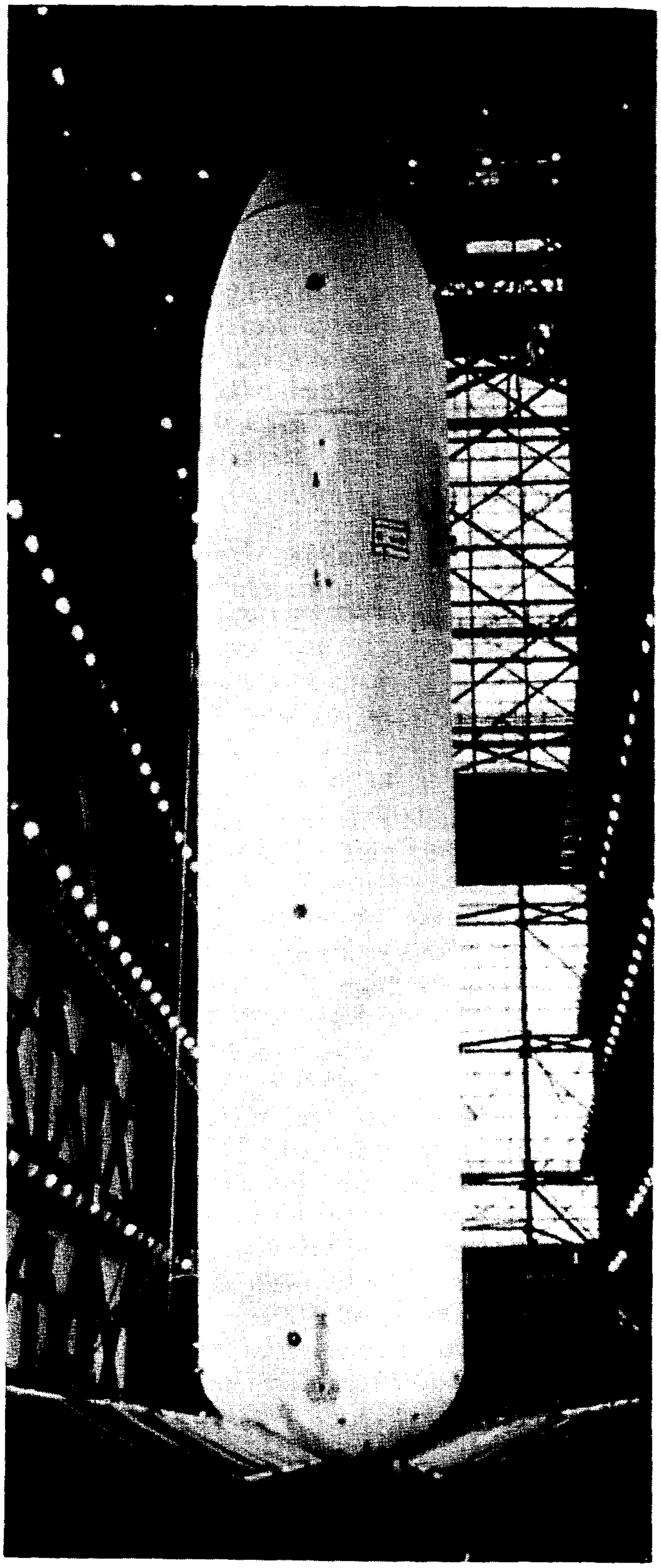
- The continuous propellant mix process with its long piping lengths may prove to be less reliable than the batch process.

- There will continue to be a single source for the acquisition of the large ring forgings needed for the design.

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

External Tank (Ref: Finding #20)

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



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

Reduction In Turnaround Time/Enhanced Flight Rate

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

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

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

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

Kennedy Space Center Processing Activities

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

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

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

LOGISTICS AND SUPPORT

(Ref: Findings #22 through #25)

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

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

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

Integrated Logistics Panel Activities

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

Logistics Management Transfer Responsibility

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

Supportability Trend, Analysis and Reporting System

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

Maintenance Trend Analysis Reporting System

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

The Lockheed Shuttle Processing Contract Logistics Support Organization

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

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

Orbiter Carrier Aircraft--B-747

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

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

Cannibalization

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

Corrective Action Reports

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

Component Repair Turnaround Times

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

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

Space Shuttle Main Engine Logistics Status

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

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

Scheduled Structural Overhaul of the Orbiter Fleet

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

C. SPACE STATION FREEDOM PROGRAM

PROGRAM CONTENT
(Ref: Finding #26)

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

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

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

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

Major Changes:

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

Major Deferrals:

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

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

TECHNICAL ISSUES

Space Environmental Factors
(Ref: Finding #27)

Orbital Debris

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

Radiation Shielding

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

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

Ingress and Egress (Ref: Finding #28)

Space Shuttle - Space Station Freedom Docking

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

Airlocks

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

Internal Environment
(Ref: Finding #29)

Toxic/Hazardous Spills

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

Fire In Zero-G

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

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

The status of spacecraft fire safety was stated as:

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

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

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

Common Berthing Mechanism

(Ref: Finding #30)

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

Extravehicular Activities

(Ref: Finding #31)

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

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

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

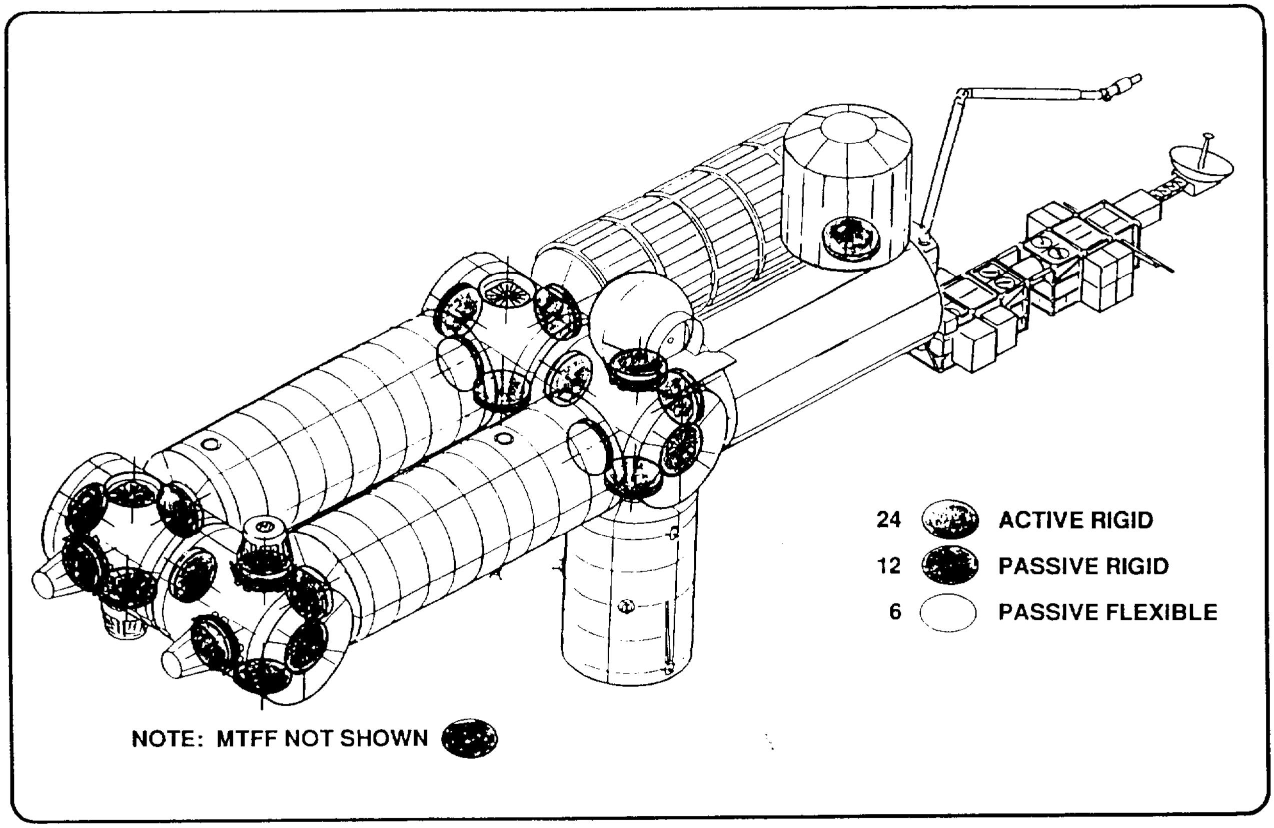


Figure 8, Common Berthing Mechanism Locations

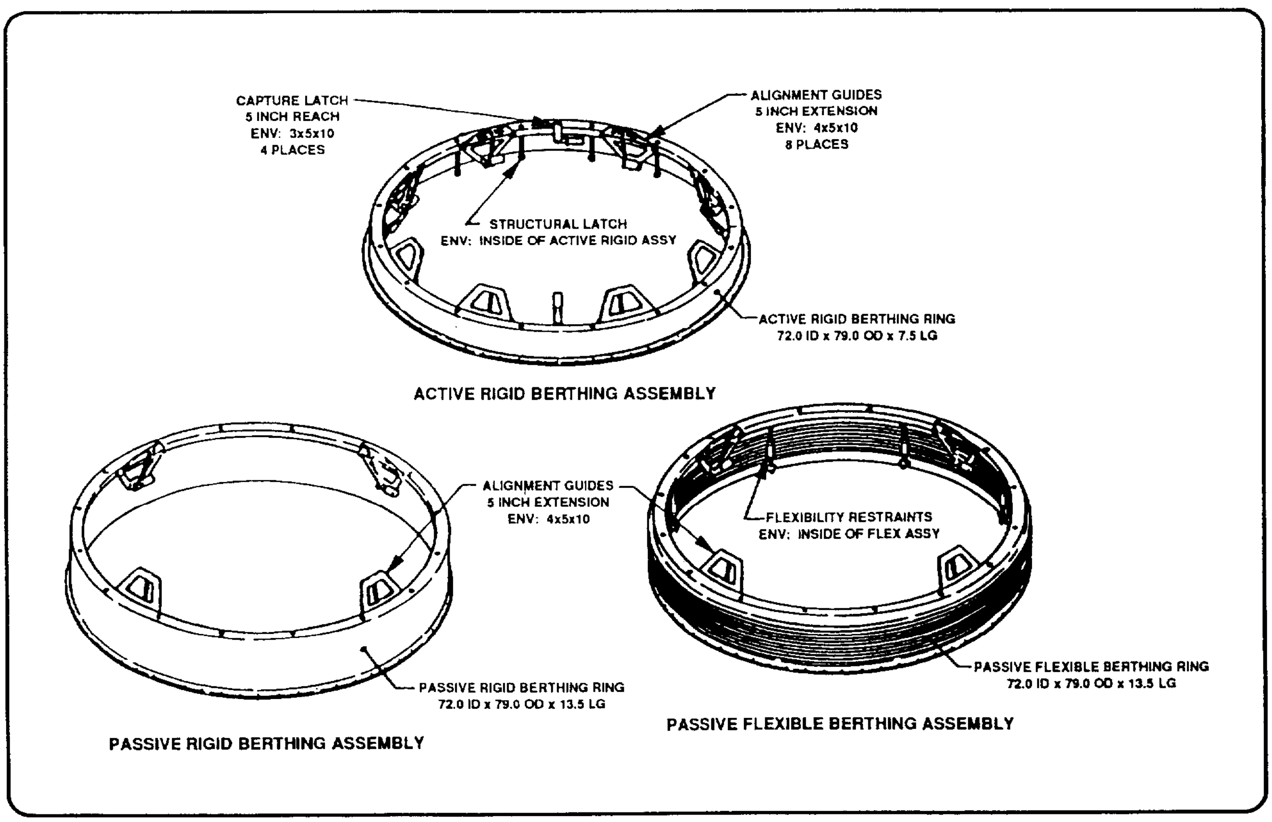


Figure 9, Common Berthing Mechanism Overview higher pressure suit that is more adaptable to the requirements of the station assembly and long-term operations. Use of the current suits places a very rigid set of requirements upon the station design, training, operations, and emergency reaction processes.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

Safety and Product Assurance

(Ref: Finding #32)

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

- The safety and product assurance organization should be situated within each level at an appropriate organizational position to assure access to program management and have enough clout to be heard within the engineering and associated disciplines.

- The safety and product assurance personnel should be a true team member within systems engineering and integration operations, since their activities (especially in the early phases of design work) are crucial to minimizing hazards and overall risks before they become ingrained in the design and operations.

- A strong subcontract management organization is required at the contractor level to assure that acceptable products come into the prime contractors.

- Total Quality Management should be considered as a normal part of the daily operations of the safety, reliability, maintainability and quality assurance organizations of all levels of the Space Station Freedom. NASA continues to have a vibrant program intended to imbue every aspect of NASA with total quality management just as is being done in other agencies and the aerospace industry.

Contingency Planning

(Ref: Finding #33)

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

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

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

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

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

Safety-Critical Functions
(Ref: Finding #34)

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

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

Space Station Freedom Computer Systems **(Ref: Finding #35)**

The Space Station Freedom will be highly dependent upon computers for its operation, and will have a very large complement of software to run those computers. These computers will operate in real time and control many other devices. There is no known theory of software testing that is adequate to guarantee that the software is correct. For the Space Shuttle, this difficult problem is dealt with thorough massive testing using actual flight computers and as much real hardware as possible. For the Space Station Freedom, the software will be much larger and more complex than for the Space Shuttle. The problem is compounded because there will be in-space modifications to the computers and software of a nature not present in the Space Shuttle computer systems. Both software and hardware will have to be upgraded without being returned to the ground, and flight experiments will require regular changes to the distributed computer system.

Original plans for Space Station Freedom software testing included building a large test facility in which software could be tested in an environment that would represent the environment of the Space Station Freedom itself. Initially, it was intended that the test environment would consist largely of the various Space Station Freedom components, with actual hardware included where feasible. More recently, the form of the testing facility has been altered to replace hardware with simulations.

LOGISTICS AND SUPPORT

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

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

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

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

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

Figure 10, Space Station Logistics

- Technical data and computer resources.

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

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

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

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

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

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

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

D. AERONAUTICS

AIRCRAFT MANAGEMENT
(Ref: Findings #36 and #37)

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

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

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

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

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

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

AERONAUTICAL RESEARCH

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

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

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

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

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

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

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

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

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

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

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

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

E. RISK MANAGEMENT

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

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

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

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

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

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

The Space Shuttle Program has a need to monitor the aging of components and their reliability as a function of time in service. This typically is accomplished with fleet leader statistics. Unfortunately, as presently employed, fleet leader numbers can be relatively uninformative or even misleading. For example, these data do not permit managers to assess whether the fleet leader is representative of the entire system or simply an outlier. Statistics on single fleet leaders should be augmented by simple data that identifies the distribution of the entire fleet. For items procured in relatively large numbers, this might be expressed as 25th, 50th (median), 75th and 95th percentile figures. For relatively unique items, information on the three or four oldest and youngest item might be provided.

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

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

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

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

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

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

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

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

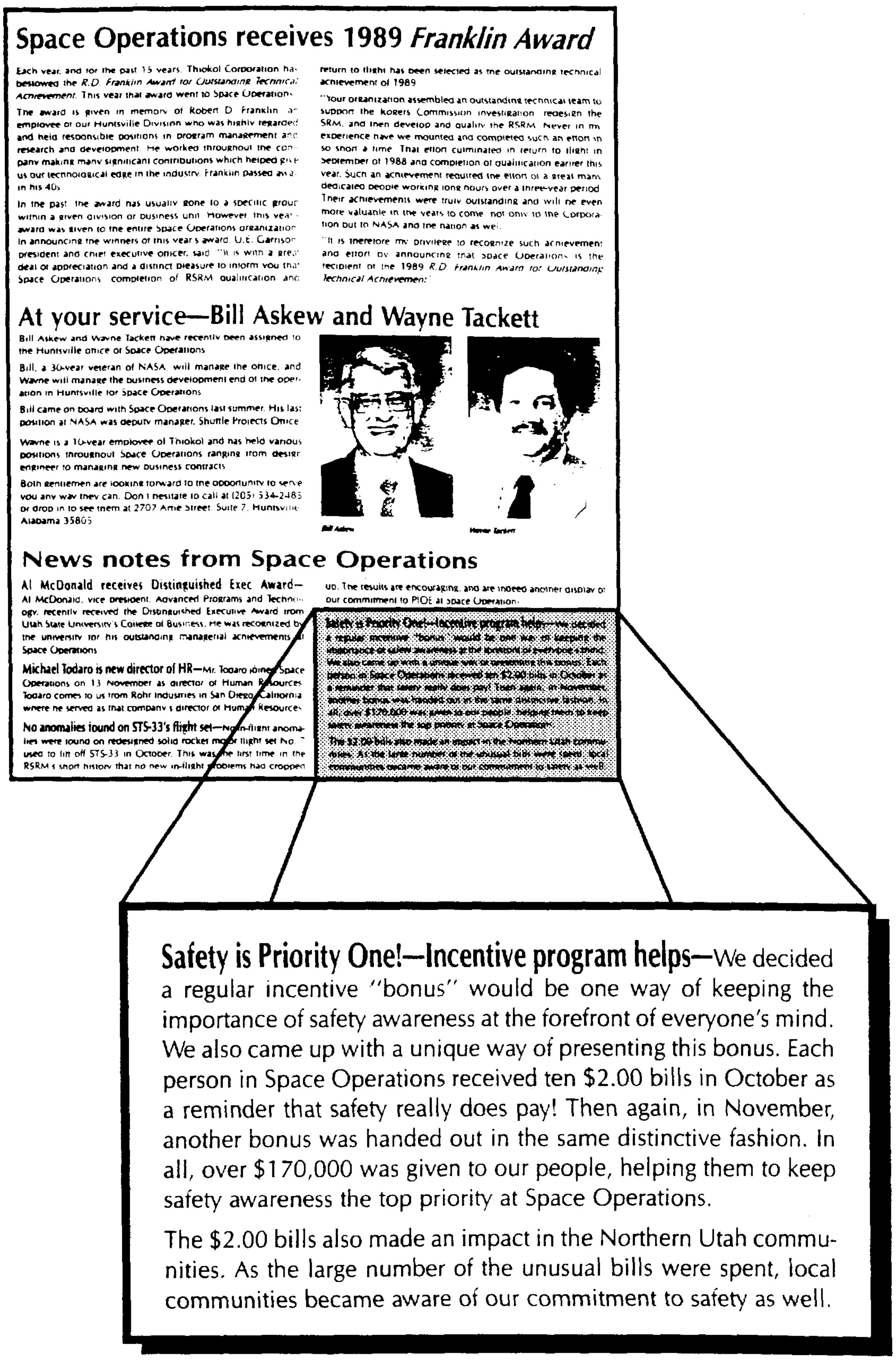
For Sucher's group, it's working!

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

- Vice President Production
  - Case Insulation and Lining Work Center
  - Propellant Mix/Cast/Cure Work Center
  - Nozzle Work Center
  - Final Assembly Work Center
  - Component Refurbishment Work Center

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

Figure 11A, Space Operations Review



Space Operations receives 1989 *Franklin Award*

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

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

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

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

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

At your service—Bill Askew and Wayne Tackett

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

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

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

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

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

Bill Askew

Wayne Tackett

News notes from Space Operations

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

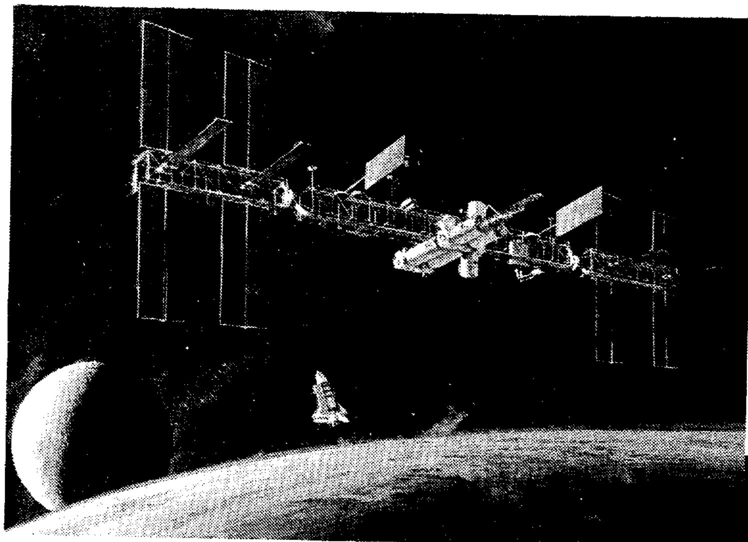
Michael Todaro is new director of HR—Mr. Todaro joined Space Operations on 13 November as director of Human Resources. Todaro comes to us from Rohr Industries in San Diego, California where he served as that company's director of Human Resources.

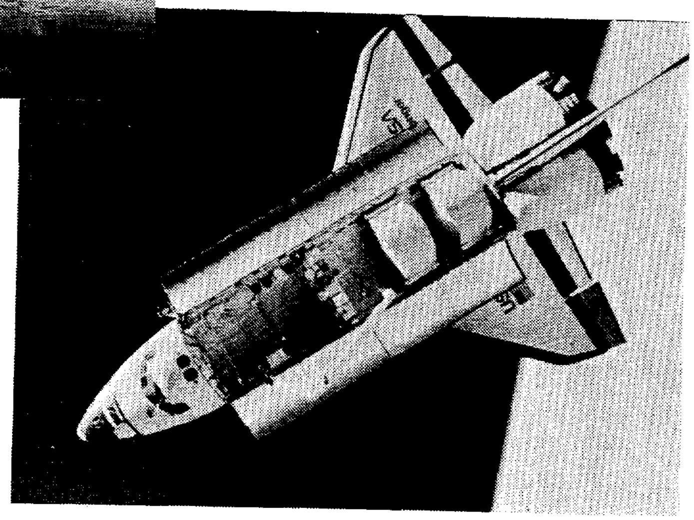
No anomalies found on STS-33's flight set—No in-flight anomalies were found on redesigned solid rocket motor flight set No. 7 used to lift off STS-33 in October. This was the first time in the RSRM's short history that no new in-flight problems had cropped up. The results are encouraging, and are indeed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

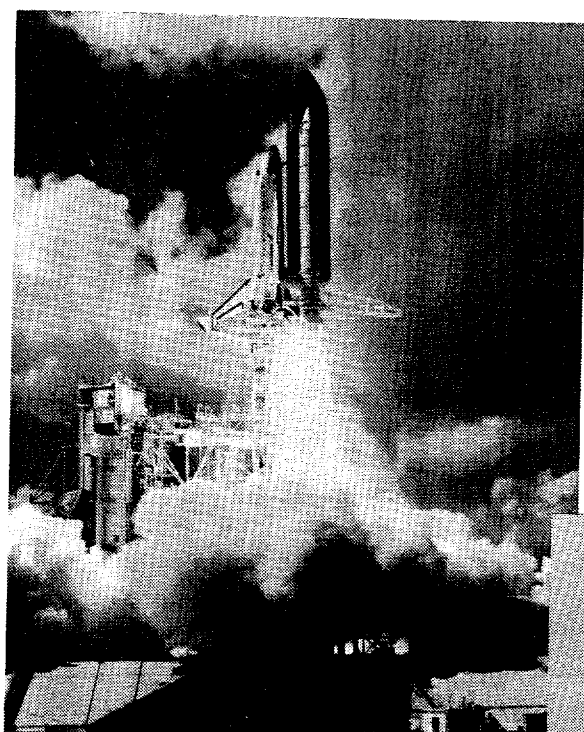
Safety is Priority One!—Incentive program helps—We decided a regular incentive "bonus" would be one way of keeping the importance of safety awareness at the forefront of everyone's mind. We also came up with a unique way of presenting this bonus. Each person in Space Operations received ten $2.00 bills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

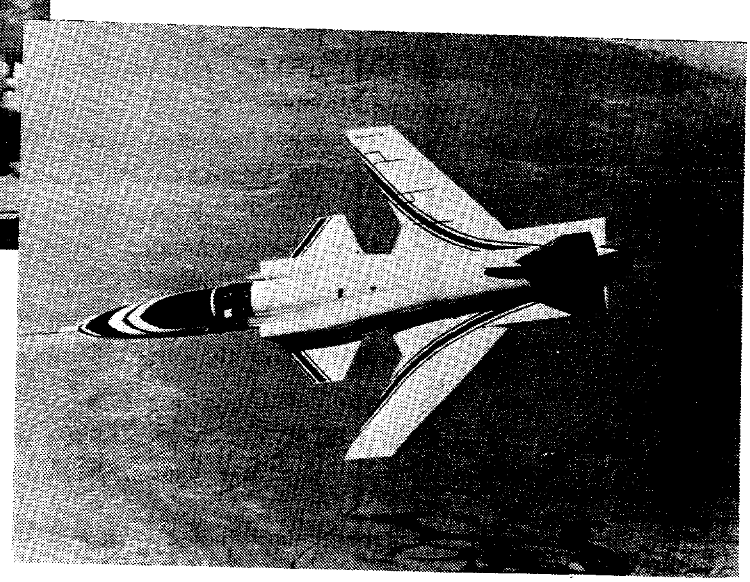
The $2.00 bills also made an impact in the Northern Utah communities. As the large number of the unusual bills were spent, local communities became aware of our commitment to safety as well.

Figure 11B, Space Operations Review









IV. APPENDICES

A. NASA AEROSPACE SAFETY ADVISORY PANEL MEMBERSHIP

CHAIRPERSON

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

DEPUTY CHAIRPERSON

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

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MR. CHARLES J. DONLAN
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MR. GERARD W. ELVERUM, JR.
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TRW Applied Technical Division

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

MR. JOHN F. MCDONALD
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DR. JOHN G. STEWART
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DR. RICHARD A. VOLZ
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MR. RICHARD D. BLOMBERG
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MR. I. GRANT HEDRICK
Senior Management Consultant
Grumman Corporation

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

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

EX-OFFICIO MEMBER

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

STAFF

MR. GILBERT L. ROTH
Staff Director

MS. PATRICIA M. HARMAN
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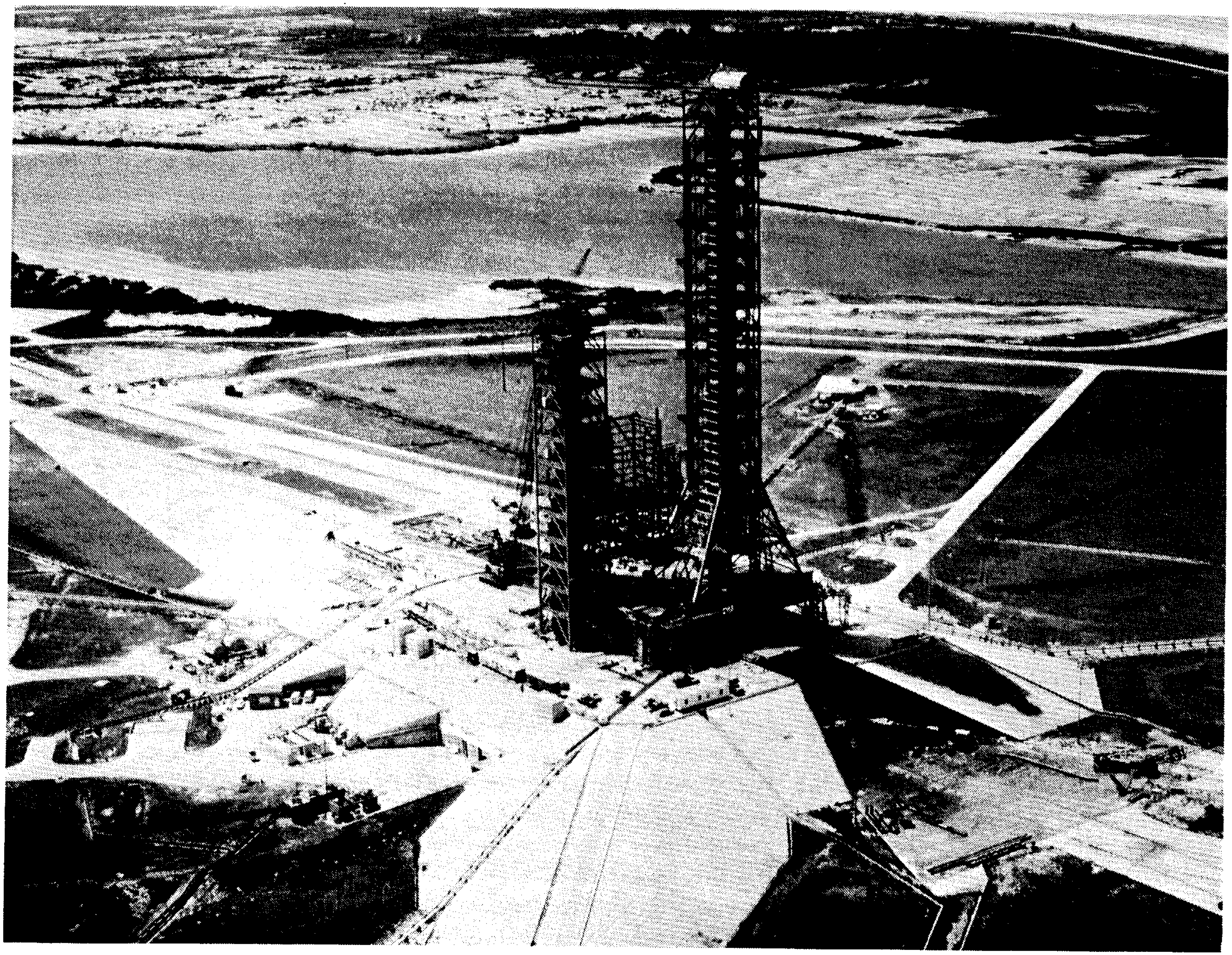

B. NASA RESPONSE TO MARCH 1989 ANNUAL REPORT

<u>SUMMARY</u>

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

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

1. Orbiter OV-102 strain gage calibration (page 41, C.3.a.).

2. Crew emergency rescue vehicle activities (page 47, D.2).

3. Aircraft operations and safety management (page 49, E.4).

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

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

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

NASA

National Aeronautics and
Space Administration

Washington, D.C.
20546

Office of the Administrator

JUN 26 1989

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

Dear ~~Mr. Sutter~~ Joe-:

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

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

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

Sincerely,

Richard H. Truly
Acting Administrator

Enclosure

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

Dick

II FINDINGS AND RECOMMENDATIONS

A. NATIONAL SPACE TRANSPORTATION SYSTEM

1. Management Structure

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

2. **Safety Enhancements**

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

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

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

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

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

3. Advanced Solid Rocket Motor (ASRM)

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

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

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

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

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

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

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

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

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

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

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