annual report to the nasa administrator by the aerospace safety advisory panel on the space shuttle program

part I —observations and conclusions

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ANNUAL REPORT TO THE NASA ADMINISTRATOR

by the

AEROSPACE SAFETY ADVISORY PANEL

on the

SPACE SHUTTLE PROGRAM

Part I - Observations and Conclusions

ALT Flight Readiness
OFT Development Status

March 1977

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INTRODUCTION TO OPERATING PHILOSOPHY

This introduction is written for the reader who may be unfamiliar with the Panel's role and to inform traditional users of the Panel's report of changes in our operation.

The Panel is created and chartered by Congress as a senior advisory group to NASA management, most specifically the NASA Administrator. The members are appointed by public law for six-year-terms. The criteria for their selection include executive experience and knowledge of the requirements of running large organizations where development programs have inherent risks and appropriate policies have to be evolved. Members must also be sensitive to the accountability requirements facing senior public officials.

The Panel conducts its work as spelled out in the NASA policy on the Panel:

> "Pursuant to carrying out its statuatory duties the Panel will review, evaluate and advise on those program management policies, management systems, procedures and practices that contribute to risk identification and assessment by management. Priority shall be given to those programs that involve the safety of manned flight." (NMI 1156.14C)

Through its inspections, the Panel requires project management at both NASA and contractor levels to review and explicitly explain their technical management system and decision making processes, the basis for confidence in crew safety and the rationale for risks that have to be accepted. On Apollo, Skylab and ASTP the Panel principally operated through on-site inspections by the full Panel. The Panel, however, augmented its approach of full Panel inspections with detailed fact-finding by specific teams and designated individuals. This was done in order to gain greater visibility into significant areas on Shuttle.

The Panel's approach reinforces and supports decision making that minimizes crew risk and serves to assure problems are worked in a timely manner and at the lowest appropriate management level. The Panel's report to the Administrator and Congress seeks to provide them independent assessment and substantial information to aid them in their oversight responsibility and keeps before senior flight management's attention those issues critical to crew safety. The Panel thus contributes to (1) policy formulation, (2) program planning and accomplishment of program objectives more effectively, (3) agency management decision making, and (4) achievement of economies in the program. Examples are cited in the report to the Office of Management and Budget, Appendix A. More detail is provided in the Space Shuttle Program's response to the 1976 Annual Report, Appendix B.

The Panel is very much aware of its continuing responsibility to Congress and is pleased that the House Committee on Science and Technology found the Panel's 1976 Annual Report useful for their own review. The Committees "Space Shuttle 1977 Status Report" states that the Panel's independent review and 1976 report "noted a number of critical areas and recommended actions to be taken to strengthen the program. In making this (the Committee's) current review, the Panel's comments were noted to aid in assessing the posture of the Space Shuttle Program." As the report notes, the first topic discussed in the issues section of this report is one that had been examined by the Panel.

One of the Panel's objectives is to provide timely reports that add to both the public's informed understanding and the development of appropriate criteria of public accountability. Thus the Panel submits a comprehensive report.

With its responsibilities to NASA, the Congress and the public in mind, the Panel submits this report. The report reflects the Panel's concentration on areas critical to a successful Approach and Landing Test Program (ALT) in 1977 as well as the critical elements for the Orbital Flight Test Program (OFT).

The primary goal of the Approach and Landing Test (ALT) program is to gather sufficient flight test data to verify safe Orbiter subsonic aerodynamic flight and landing with an Orbiter and ground operations configured as closely as practical to the hardware and software to be used in the approach and landing phase of orbital missions. The Panel focused on those ALT activities which provide certification of the required program elements.

Thus the Panel reviewed the following areas of major significance for ALT: mission planning and crew training, flight-readiness of the Carrier Aircraft and the Orbiter including its flight control and avionics systems, facilities, communications and ground support equipment, and the management system for risk assessment. Our observations and recommendations are consolidated into the first two chapters of this report. The chapter on mission operations includes an assessment of mission management, mission planning, communications and ground operations. The chapter on vehicles for ALT includes an assessment of the Shuttle Carrier Aircraft (modified 747) and the Orbiter including the critical avionics and flight control system.

While the Orbital Flight Test Program (OFT) is scheduled to begin in 1979 the major elements are now in an advanced state of design evaluation, manufacturing and assembly. Our observations and recommendations are consolidated into chapters on the Orbiter and the principal elements of the Shuttle propulsion system, i.e., the Main Engine, the External Tank and the Solid Rocket Booster.

The first volume contains the Panel's observations and recommendations and the second volume gives the supporting detail and summarizes the results of the Panel's inspection activities.

As for the work plan for the current year the Panel plans to provide flight-readiness assessment reports on each phase of the ALT test program where there is a significant new risk. Thus the Panel plans to submit short reports on (1) the first mated flight with the captive Orbiter manned and its systems active, (2) the first separation, approach, and landing of the Orbiter, and (3) the first captive flight of the Orbiter in the orbital configuration without a tailcone. This will also be a major year for activities on the principal elements required for OFT since these are only two years from first flight. Furthermore, this is the time for the significant Critical Design Reviews as well as preparations for major ground tests to prove the designs.

ALT MISSION OPERATIONS

A. OBSERVATIONS

It is important to begin by noting that one of the goals of ALT is to configure mission and ground operations as closely to the approach used in the approach and landing phase of the orbital mission since that goal explains the management concept that put the flight of the vehicle under JSC direction and ground operations under KSC although the flights were physically to take place at DFRC. The Panel's initial thought was that it would have made management and communication simpler if the total operation would have been under DFRC control but we recognize the tradeoff and focused on how the management concept would be made to work.

This concept meant that a suitable organizational approach had to be implemented to direct and coordinate these efforts and we found that the Shuttle program had created a dedicated project organization with a sound management system.

JSC "controls" the activities at DFRC including the checkout and the actual flights. The checkout is accomplished through the ACE station which is at Rockwell's manufacturing facility at Palmdale. Thus during checkout there will be data links from the Orbiter and support equipment at DFRC to Palmdale, Downey and JSC. As for flight control the combined active 747/Orbiter and active orbiter flying alone will be under direct JSC's Mission Control Center at all times. This has the advantage of exercising the communication and computer facilities at

JSC much as they will function during OFT and later operational flights. The 747 when separated from the Orbiter will be under DFRC control. The flights of the 747 mated with the inert Orbiter, which were flown in February and March 1977, were under DFRC control at all times.

Our review of the reliability of the complex communications system to support a mission with a manned active Orbiter found that the program's policy is that any loss of communications between the carrier/Orbiter and JSC prior to separation will result in a decision not to separate the Orbiter. Loss of communications after separation is apparently an acceptable risk and it is assumed the Orbiter can continue landing with no further assistance from JSC. Although there are redundant systems that make such a loss improbable, the Panel questioned the economy of eliminating DFRC as support center for an Orbiter approach and landing.

The program's position is that tests of the communication system should provide adequate confidence in its reliability. There are no known reasons to doubt that the crew can land the Orbiter without assistance from JSC in the unlikely event of loss of communications between JSC and the Orbiter after separation. The Aerospace Safety Advisory Panel is satisfied that those responsible for the planning and testing of this system are highly qualified and well aware of potential problems. The program has been keeping ahead of scheduled requirements and have planned extensive tests to assure the performance of the system. The comments in the recommendations are suggestions to enhance the margin of safety that is acknowledged to be there.

The Panel, in considering the approach to mission planning, found that the ALT program's objective is to progress in minimum steps consistent with flight safety from test conditions that provide the greatest margins of safety to test conditions anticipated in the first OFT approach and landing. This is a reasonable and prudent approach to taking the necessary risks to meet the program objectives. We found the management system made effective use of special working groups - such as the Flight Techniques Panel to coordinate the efforts of those involved in designing mission objectives and flight techniques to meet program objectives and to surface and resolve issues originating in differing viewpoints.

Also, the Panel has been in a continuous discussion with the program on the planning of crew training. For instance, the Panel is pleased to learn that NASA utilizes the simulator at Ames. Here again our recommendations are to enhance a program that is reasonable.

Finally, the Panel has reviewed the facilities and GSE associated with mission operations. Of special note is the method of lifting the Shuttle Orbiter and the facilities for attaching it to the 747. The plans for checkout appear to be adequate but will require continual surveillance since the system contains several single-point failure possibilities which could cause major damage.

Any program like ALT with so much experimental dimension in it will require changes along the way and this will too. Therefore, the Panel plans to review mission operations for each phase of the ALT program before it begins in light of the experience from prior missions and the new requirements for that phase. Our objectives will be to assess within the limits of our resources the degree to which:

1. The program management system has defined a set of mission rules and a flight plan that provides a reasonable basis of confidence that the nominal flight plans can be successfully executed.

2. The flight planning process has used a conservative approach in planning the nominal mission and providing for contingency and abort situations including emergency separation and jettison.

B. RECOMMENDATIONS

1. In the lifting body flights, the pilots were substantially assisted by calls from the control room where a pilot was available showing the actual location of the vehicle as compared with the planned locations. The Panel is very impressed by both the simplicity and effectiveness of this "modified GCA" in assisting the busy pilot on these short flights. For ALT it is understood that such a plot is planned at Mission Control JSC. It appears prudent to maintain the same plot at DFRC as a backup in the event of the highly unlikely but still possible loss of voice communications between Houston and Edwards. The Panel wonders what penalty the ALT would encounter by including this already available backup system.

2. The closest actual experiences to the ALT flights are those that were gained during the lifting body and earlier rocket aircraft flights. We should not overlook any opportunity to use this background wherever appropriate. For example, it is suggested that lifting body pilots be requested to fly the STA and Orbiter simulators and provide

comments on their flight experiences. Similarly, it may be useful to have a general critique of ALT mission plans by a group of experienced personnel who have not been involved to date. This group might include such people as Chuck Yeager, Bob White, Bob Rushworth and lifting body engineers of AFFTC.

3. The Panel suggests that crew training might be enhanced by the use of additional existing simulators with capabilities different from simulators now being used. For example, the Air Force simulator (AFFTC Engineering Simulators) at Edwards AFB has proved very valuable for lifting body training. The Air Force simulator is not as comprehensive as other such training devices, but changes in aerodynamic values are easy to accomplish and should be useful in pilot training. Also, interaction between Air Force and NASA personnel would be enhanced.

4. Experience in lifting body simulator training and missions show that pilots are able to accomplish tasks at a higher rate in the simulator than in actual flights. Use of "fast time" simulators for training is one way of insuring that the pilot is not overburdened in flight. It is recommended that the use of such a simulator be given further consideration.

THE VEHICLES FOR ALT

A. OBSERVATIONS

The ALT program calls for the following phases: (1) mated flight of the Shuttle Carrier Aircraft (modified 747) with an inert unmanned Orbiter, (2) mated flight with the captive Orbiter manned and systems active, (3) separation and landing of the manned active Orbiter with its tailcone on, and (4) approach and landing of the Orbiter in its orbital configuration without the tailcone.

The Panel has been monitoring the testing on the Shuttle Carrier Aircraft (747), Orbiter 101 and the mated configuration through its own inspections and fact-finding as well as attendance at internal program reviews such as the Critical Design Review and the Customer Acceptance and Readiness Reviews conducted for the actual flight hardware. It appears that the program to modify the 747 into the carrier aircraft has gone well and the Panel sees no critical areas for top management attention.

The Panel has reviewed the readiness of the Shuttle Carrier Aircraft and inert Orbiter for the first phase of the flight test program. It appears to us that the primary elements of the total system are in a development and test status so that this flight may be conducted in a safe manner.

Specifically, the 747 modifications appear to be complete and the risks due to this part of the system well understood and controlled by the planned flight program. The Orbiter and its attachment to the 747 appear to be structurally adequate under the conditions planned for the test. The flight plan which includes simulation of the eventual drop altitude and velocity is calculated to not load either the Shuttle Orbiter or 747 airframe beyond prudent limits (0.75 of the design load).

After this flight phase, the Orbiter will go through a modification and test period to prepare it for operation as a manned active system. As can be expected there is substantial work to be completed before the vehicle is ready for certification. The readiness of the total system is dependent on the completion and validation of all critical elements including the avionics and the flight control system.

During the early part of the year the major concern about the avionics system was the definition of the specifications for the software and the completion of the actual software programs. The Panel finds that the emphasis put on this problem has resulted in software deliveries and testing that seem to be adequate for the ALT tests. In these tests the demands on the avionics system will be relatively simple and of short duration. The system, in increasing complexity, is being extensively simulated at JSC, Downey and in the 101 vehicle. We think that the software is acceptable unless last-minute changes are made that cannot be adequately verified because of time. It should be pointed out that the software is not being independently verified, but is being validated by repetitive exercising in the course of component and system testing. This is not necessarily bad, but we are doubling up the validation and verification which must be carefully monitored.

The program for the backup flight control system is in good shape with a lot of experience, because it was delivered relatively early and has been used extensively in the early testing programs.

During the latter part of the year testing was begun in earnest using the new programs running in the 101 vehicle as well as the simulation laboratories. As might be expected, problems began to surface with the actual flight hardware.

The computers themselves seem to have their share of hardware problems, but they do not seem to be of a generic nature and should not be critical. However, the recent power supply problem should be evaluated.

The balance of the hardware shows some problems in individual units, but should not affect a satisfactory ALT test. The fact that the testing is rather late in the game is more responsible than the inherent quality of the hardware operating under the short time, relatively simple ALT missions.

Currently the problems being experienced are largely those related to the total systems operation in real life. The vehicle itself (101) has physical characteristics of its own that affect feedback and system response that must be ironed out by either soft or hardware changes. The problem is one of tight scheduling, and the time needed to do the testing necessary to get the system to an acceptable performance level for ALT. The first round of system problems is under correction and will be checked in the simulators and labs and then put back in 101 for verification and, hopefully, only fine tuning will be necessary. At this time, from an avionics point of view, we would expect the program to achieve the ALT schedule, particularly since the first unmanned captive flights do not require active avionics, although they may well impinge on testing time necessary for later ALT flights.

Thus, the Panel's assessment of the avionics system is that it will be ready and acceptable for the limited demands of the ALT program. The step-by-step nature of ALT enhances the confidence in the avionics adequacy. The testing in the various simulators as well as in 101 is rapidly building up the necessary verification time of the avionics system.

The hydraulic and flight control system has, of course, been the subject of intense reviews since the recent failures during design testing and the basic design concept is to make it a fortress rather than failure tolerant.

Recent test failures indicate that seal leakage could drain the hydraulic system making it useless. The modifications for ALT include strengthened primary seals, the addition of backup seals and the addition of a reservoir system so that any leakage would be slow enough for the system to be refilled by the reservoir until there was a safe landing. We agree with the need for these mods and agree that such mods satisfactorily reduce the risks in that part of the system so it can be used safely on ALT. The Panel concurs with the Williams' study that concept changes in elements of the control system should be considered for orbital operations.

NASA's senior management is to be commended for the comprehensive review of the system they authorized and the review done by NASA's Chief Engineer, Walt Williams, and his team of non-NASA experts. The Panel agrees with the priorities of concern suggested by the Williams' group. The recommendations that follow reflect our concerns.

The Panel has given particular attention to the APU which provides the power for the hydraulic system since it will be used longer on the active Orbiter flights than on orbital flights and a failure could deactivate all controls. Further, in order to assure sufficient fuel for the ALT missions the APU's will be started, stopped and restarted during the mission. The program's position is that the APU fuel capacity usage is directly dependent on the time histories of actuator valve responses commanded by the avionics. Detailed simulations and validation on ADL/FCHL and SAIL of the total hydraulic flow requirements over a mission are being conducted. Test data is being evaluated. The results of these studies and simulated flight demonstrations will identify any deficiencies in capacity.

Our recommendations on this system and other elements of the flight control system are noted below.

B. RECOMMENDATIONS

1. The Panel acknowledges the massive and dedicated effort applied to the avionics system during last year and can only recommend the continued use of the simulators and Orbiter 101 to build up the testing experience the extent of which is the only real verifier of a hardware-software system.

2. If the modified actuator system is not installed in time

for the regularly scheduled integrated tests, a special thorough end to end integrated test of the hydraulic system should be required for certification of flightworthiness for ALT.

3. Parasitic uses of the main hydraulic power systems are not considered to be acceptable in most modern aircraft practice without careful attention to isolation systems, and should be minimized or eliminated if possible by provision of special power systems before the first free flight of the Orbiter (ALT). It would appear that there are reasonably simple solutions for all such individual systems (brakes, nose wheel steering, etc.). It is possible that on ALT the reservoir can handle the largest expected leak.

4. The APU's are on a very tight schedule but their thorough certification must not be short circuited. Further, the Panel suggests serious consideration of a backup source of hydraulic power and added fuel capacity so that starting and stopping of the APUs in active ALT flights are not necessary.

5. Orbiter software presently limits control surface movement rate to 20° per second. The Panel recommends that changes in software be considered to permit an increased rate of movement. Experience in the X-15, X-24, YF 16 and B-1 graphically illustrated that flight control problems can result from restrictive rate limits. It is understood that hydraulic system capacity may become a limiting factor for control surface. If simulation with higher rate control surface movement suggests any kind of capacity restraints on the control of the Orbiter an increase of capacity should be considered along with other hydraulic systems modi-

fications now being contemplated.

6. Ejection seat tests (sled tests) should be completed for velocities up to launch speeds before the first manned flight of the Orbiter 101 on the 747.

7. The landing gear system is critical and system ground tests are essential to confidence in the time and certainty of drop. The Panel feels that nose gear shimmy is as critical as extension. Nose gear shimmy will be checked at the contractor and NASA's Langley Research Center before free flight. The program feels a more pressing concern is the completion of the qualification test with static loads and the test of the nose gear door thruster on the simulator. The Panel recommendation is that management review the requirements and results of the certification program.

8. The Panel has consistently emphasized that a "tail fairing Off" flight is one of the most persuasive reasons for the ALT program. This test should not be scrubbed for the reason of further need for the 101 vehicle. It should only be scrubbed if it is determined that buffet levels on the 747 are too high for safety and no alternative method of running the test can be devised.

In this respect we again note the fact that the ALT test program is so success oriented that any major problem, causing delay, might well suggest curtailment of ALT. We realize that 101 is to go to Marshall on a tight schedule, but would be concerned if meeting that schedule (or others) resulted in cancellation of tailcone-off flights or the scheduled tailcone-on flights. One step that can be taken is to assure immediate analysis of data after each ALT flight so as to permit rational decisions before the next flight. This may permit consolidation of test objectives on one or more of the tailcone-on flights, thus providing time for tailcone-off flights. Prompt data reduction and analysis will also provide opportunities for the crews to integrate revised procedures in the simulator prior to next flight. The Panel understands that JSC is aware of and addressing this need.

ORBITER 102

A. OBSERVATIONS

The Orbiter vehicle scheduled for the Orbital Flight Test (OFT) program is now proceeding through design evaluation, manufacturing and assembly. During this past year the Panel focused on the progress of such critical systems as the flight control system, avionics, the external thermal protection system and the electrical power and environmental control system.

Our assessment of the flight control system was outlined in our discussion of the system for ALT. Our basic observation is that more significant modifications may be required for OFT than the make work changes for ALT. These are discussed in the recommendation.

While there are challenges to certifying the avionics system for ALT, the Panel feels the more significant challenges are in the certification of the system for OFT. During the year the better definition of software requirements pointed up the fact that while the current system would support ALT it would not support FOF without drastic curtailment of FOF's enhanced requirements or, conversely, an enlargement of the computer memory. This situation led to a decision to design and build a new computer with an expanded memory called "double density." While this decision does not necessarily imply that entirely new and different software must be built, it will be important to make as much use of the ALT programs and test results as is possible in order to establish confidence in the avionics system for FOF. This could well turn out to be a future schedule constraint if not carefully monitored.

The design and manufacturing of the thermal protection system underwent major review this past year. Decisions have been made on the basic materials, coatings, optical properties and waterproofing processes required for each of the three types of insulation. The process to produce tiles of the desired properties seem to have jelled and the production facilities will be on line. The question about the capability to deliver follow-up sets in the desired short time still remains since the production of one set takes a year. The method of installing and bonding tiles in blocks or arrays of 160 to 200 tiles has merit. The problem of installing close-out tiles between arrays has also been solved. Earlier discrepancies in tolerances of some important dimensions have been resolved now that there is an improved flow of information between all the involved parties. The flatness of the coated surface of the tiles is defined and achievable in the manufacturing process. The radius of the rim of .060 inches is obtained by a simple chamferring and the subsequent flow of the coatings in the manufacturing process.

Testing is probably the biggest challenge at the moment. Failures of different test configurations under varying environments indicate the need for continued evaluation of the many different tile arrangements to assure they meet minimum requirements. Time to verify critical details is limited. Funding constraints last year caused a reduction in testing and may force a curtailing of testing again this year. The certification activity for all TPS design details needs special attention and rigorous screening before the first OFT. Due to lead time involved in updating test articles, test articles sometimes do not represent the final vehicle configuration. Validity of these tests for the purpose of certification therefore would be questionable.

It is obvious to the Panel that the most critical feature of the surface heat protection system is the assurance of closure and the integrity of the surface temperature protection system at the closure edges or hinges. The current major problem being addressed by program management is the configuration of the elevon hinges. The Panel agrees with the approach of having dual heat protection at the control surface hinges. The Panel has noted that efforts are being made to plan tests of the equivalent of hinge configurations and door edge mismatches or gaps in an environment approaching that of reentry. If such simulations can be achieved the Panel would support such tests enthusiastically.

There are two other areas to which the Panel will give particular attention in the coming year.

The JSC Technical Assessment Office has presented an analysis of the control capability for the reentry phase of the mission that shows a sufficiently narrow margin of controllability. **The Panel will** follow carefully all further analyses and subsonic correlation of flight data. If acrodynamic control margins deteriorate further redesign may need to be considered.

History on fuel cells for electrical power has been sufficiently good that nearly all reviewers put complete reliance on the concept. The Panel does not question the selection of the electrical sources themselves but does note that electrical power is vulnerable to a congential failure. The Panel will continue to review the fuel cells and members will review how the three cells are utilized when one or more shut-downs must be accommodated. Our comments on the environmental control system are more in the form of recommendations to provide back-up to what appears to be good systems.

B. RECOMMENDATIONS

1. The Panel is particularly concerned that the condept of parallel or tandem multiple chamber pistons for elevon actuation be seriously considered for incorporation in the planned modification of the control system. If adoption of such a revised control system should be elected, the design and development program would need to be started immediately.

2. The rudder/speed brake actuation system deserves a thorough review for vulnerability to single point failure. For instance, a failure in one of the motors used to position the rudder speed brake could cause an overload on an adjacent motor causing the failure of all the motors in a zipper fashion.

3. Increasing the APU fuel capacity on Orbiter 102 should be seriously considered.

4. The concept of hydraulic control of the main engines needs a critical review both for the effect on the hydraulic system and to ascertain that the operation of the main engines is not subject to shut down due to "service" system failures when the engine itself is still operable. Inherent in such a reassessment should be a review of the desirability and potential methods for isolating the engine control system after the

main engines have fulfilled their function.

5. The Panel would recommend that the new computer development with the double density memory system be closely monitored so as to assure the maximum compatability with the present hardware and software. This will insure a backlog of experience from ALT to aid in the verification of the software programs for the new computer.

6. Currently there is very little experience to predict the behavior of the thermal protection system in hypersonic flow and therefore the system cannot be certified by similarity or analysis. Among the areas that are particularly unpredictable are:

a. The gap configurations in width, its direction with regard to the surface flow.

b. The steps between tile and its tripping influence on the boundary layer into turbulence.

c. Flow in door seal cavities and gaps.

There will be a multitude of sub-size tiles interfacing the HRSI with the RCL of the nose-cap and the leading edge segments. These tiles will probably behave differently from the standard size tiles in the airflow. Therefore, the behavior of the patchwork surface and the effects of surface condition, gaps, or steps, etc. still appear to need test exposure to the environment for valid certification.

7. The HRSI insulated umbilical doors are exposed to the flight environment on ascent. After separation the doors will be closed. There is no inspection mode or access planned to assure a proper closure. Consideration should be given to an on orbit inspection and repair of

the TPS and particularly the umbilical door seals to assure a safe reentry.

8. The currently developed engineering criteria for TPS coating erosion and inspection method should include access feasibility studies.

9. The integrity of the aluminum structure after any flight depends on the cooling efficiency of the GSE equipment after landing and the novel design of cooling ducts to prevent the orbiter structure from excessive temperatures. The design and implementation of such a cooling duct system has not yet been certified by a total system test and should be.

10. It appears that, as a result of a good reliability history, the maintenance of cabin atmosphere integrity has been based on a "two engine" concept. This has the practical result that any failure will cause the termination of a mission in order to protect the crew from a subsequent single failure. This suggests that systems which must last through the total time of a mission probably should be augmented so that such single failures do not force mission termination for safety.

11. The flash evaporator used to supplement radiator cooling is of the "fail safe" variety like the environmental system where a single failure will abort the mission in order to maintain safety. A policy should be considered to insure that such system failures will not abort extensive missions in the name of safety.

MAIN ENGINE

A. OBSERVATIONS

Development of the Main Engine is, as most everyone is aware, behind schedule. The SSME Critical Design Review was held in September 1976. Because of development problems, particularly in turbomachinery, a number of milestones that were to have been met prior to the CDR had not been achieved. Since then much progress has been made in solving the turbomachinery problems and rated power levels have been reached. Significant improvements have been made in pump performance. Suction performance of the pumps is yet to be demonstrated. The long-lead parts of the turbo-machinery have been released for production. In some instances, backup designs have been released in parallel with the baseline design. With respect to design and performance, the situation is much better than it was a year ago. While considerable progress has been made, the SSME was from four to six months behind its schedule as of late February 1977.

Here then is our assessment of the major elements of the engine system. As noted, the turbomachinery has been the most troublesome portion of the engine development to date. The problems encountered include subsynchronous whirl and turbine bearing problems in the HPFTP, performance problems in all rotating machinery and, most recently, significant turbine tip seal erosion in the high pressure fuel and oxidizer pumps.

Stiffening of the HPFTP shaft and a modification to the cooling system for the turbine bearing have permitted the achievement of RPL for up to 61 seconds. All told, about 132 seconds of operation at RPL has been accumulated. It would appear that the whirl and bearing problems have been brought under control. Significantly longer and repeated testing is required, however, to confirm these observations and provide confidence in the design.

Performance of the pumps and turbines has been improved by decreasing tip clearances, underfiling impellers, and impeller and volute changes. The improved performance has been demonstrated on the discharge side of the pumps. Yet to be demonstrated is the suction performance of most of the pumps. A new engine power balance is to be available in mid-March. At this time it will be possible to determine whether the turbo-machinery performance has improved sufficiently to satisfy engine system requirements. It is characteristic of the cycle employed in the SSME that the performance interactions among the pumps are strong so that an assessment as to adequacy of performance must be made at the engine system level.

The turbine tip seal degradation is being attacked by a seal materials change. Indications are that the use of Bradalloy in the HPFTP may provide a fix. Doing the same to the turbine seal of the HPOTP is being considered.

At the time of the CDR, a potentially serious materials problem had surfaced concerning the low-cycle fatigue properties of Incoloy 903. Recently acquired data indicated significantly lower low-cycle fatigue life than had been used for design. Also, data from two sources did not agree. Since then, additional material properties data have been obtained and a reassessment of design assumptions, especially operating tempratures, has been conducted. It appears that the reason for the disagreement of the data is now understood. Sufficient conservatism was used in the initial design assumptions so that, upon reassessment in detail, all but four engine components have satisfactory predicted life. These four are under yet more detailed scrutiny and it appears that any required redesign will be relatively minor.

The 77.5:1 area ratio flight nozzle has been tested both at COCA 4B and on the A-2 stand at NSTL. Data that have been reduced thus far indicate that performance is within expected bounds.

Tests of the heat exchanger have begun at NSTL. Thus far, no difficulty has been encountered and early data indicate performance to be close to design predictions. The combustion systems are in excellent shape and stability testing has been completed satisfactorily. Heat transfer is measured to be within design boundaries.

Much of the auxiliary equipment has completed DVS testing. What remains to be done is on, or close to, schedule.

The controller is still performing well in the field. A firm baseline configuration has been established and unit P6 is being built to that configuration. It will be the qualification unit.

Controller software is on a very tight schedule with Block I required for MPT. At present about seven percent memory margin is available.

Although recent engine system tests had to be aborted because of temperature spikes during startup, a 61 second run at RPL was accomplished March 12th. Minor modifications to the sequence may be necessary to assure this problem is resolved.

B. RECOMMENDATIONS

1. There are no specific recommendations at this time on resolving the existing problem since the engine development problems are well recognized by the proper levels of management and solutions are being sought and evaluated. However, the deadline is near when sustained engine running time at rated power levels and start transients to all high power levels must be attained if current milestones for major tests and the certification for first orbital flight are to be met. The start-up and turbine tip seal problems must be solved quickly so that long-duration runs may be achieved over the range of power levels. Repeatability of performance in meeting test objectives and consistency of performance from engine to engine must be demonstrated within the near term in order to not impact the overall Shuttle schedule.

2. If these requirements are not met in a timely fashion the program will, of course, face important judgments as to how to guarantee the necessary test time to certify the engines for manned orbital flight. As noted in last year's Annual Report, the planned test program called for fifty-six hours of engine testing in Final Flight Configuration which compares favorably with the test time accumulated on the Saturn F-1 and F-2 engines. Contingency or recovery planning must provide management either the realistic schedule to meet such an objective or the significance of any deviations from that goal in term of the effect on the basis for confidence in the flightreadiness of the engine.

SOLID ROCKET BOOSTER

A. OBSERVATIONS

During this past year the Panel has focused on the Solid Rocket Motor (SRM) as the most significant component, while a minimum of time has been spent on other components. Other program areas examined by the Panel include test and risk assessments associated with the development and operational use of the SRB.

The Solid Rocket Motor (SRM) includes a number of vital functional components besides the basic rocket propellant and cases which form the majority of the weight and volume. The SRM nozzle, which has a diameter of 54.43 inches at the throat section, is designed to be gimballed or deflected for attitude control of the total Shuttle system during ascent. This 11 ton, 13 foot long nozzle requires a flexible bearing which is constructed of alternate layers of elastomeric rubber and steel. The hydraulic supply system, including the auxiliary power unit and hydraulic pump, drives the thrust vector control or nozzle gimballing system.

The separation system, to separate the SRB from the ET during ascent, utilizes separation rocket motors and control system that must operate on time and within performance requirements to assure total and clean separation. The recovery system is all important to the required reuse of the SRB element of the total Shuttle system.

Among the major management events this past year was completion of the Solid Rocket Booster Critical Design Review (CDR), in December

1976 rather than the originally scheduled August 1977 because of the very good progress that has been made in the design/development of the SRB overall and component parts.

This period also saw the selection of an overall assembly contractor with Marshall now assuming the same project management role as it has on the External Tank and Main Engine projects.

As for management at the contractor, the SRM project at the Wasatch Division of the Thiokol Corporation has been given a very high status in the company organization. The SRM Project Director reports directly to the Divison Vice President and General Manager. The project team consists of about 45 people including those few in the field operations at NASA Centers. Engineering, test, administrative and other critical personnel are then drawn from the 2,300 people available at the plant on an as required basis to form functional areas within the project team. Our discussions with the Thiokol personnel and the Marshall program administration and technical groups indicates that the Wasatch Division is staffed by experienced technical people at all levels. The NASA resident office is staffed by competent people doing an excellent job.

Elements of product assurance in achieving a reliable SRM include: (a) emphasizing the fact that this is to be a "manrated" system, (b) elimination of historical failure modes, and (c) sustaining personnel motivation. Thiokol reorganized so that product assurance is a single cohesive group. They are following the hazard identification and risk assessment system in use throughout the Shuttle program. This also holds true for supplier controls and auditing systems. They are disposing of approximately twenty material review board actions a week at this time. This is expected to increase as the pace of fabrication increases. It does not seem excessive now.

Thiokol has a contract with KSC to examine the hazards and risks associated with operating in VAB during the Space Shuttle build-up for flight. A first progress report was given to KSC personnel by Thiokol on September 30, 1976. It consists of three components: (a) propellant ignitibility testing and propagation testing, (b) outline of process compliance and hazard identification including probability of occurrence, and (c) consequences of ignition and recommendations (plume definition, exhaust composition, building involvement, and propagation control).

Much of the technology used in the Solid Rocket Motor has been demonstrated on previous programs and thus provide a good basis of confidence in this program.

To date over 250,000,000 pounds of the propellant used in the SRM has been produced for Minuteman motors and many others. It is basically the same with changes in the quantity of iron oxide which is used to control the burning rate. The higher the iron oxides the higher the burning rate in pounds per minute. Aging during storage has been demonstrated not to affect the viability of the propellant. Thiokol has held some 40,000 pounds in storage for over 13 years and when fired has met all specifications.

The case material, which is D6AC modified carbon steel has seen extensive use in rocket motor and aircraft applications because it has a relatively high strength and very good fracture toughness. It has been estimated that for each use or firing of the SRM the case wall thickness will be reduced by 0.00024 inches, which allows for a total of 20 firings (19 refurbishments for operational use).

The aft 4½ feet of the SRM nozzle, aft of a field splice, is severed by a linear shaped charge during the return of the SRB to the water by parachute. This segment is discarded so that the load on the structure is reduced to acceptable levels upon impingement in the ocean. Similar configurations have been demonstrated on a 156-inch motor program for the Poseidon missile.

The design safety factors for the multi-use SRM compare favorably with the ICBM. An extensive experience base exists for the characterization of materials and the use of fabrication processes that provides confidence that SRM as a whole and its components should experience a minimum of problems as they progress through the testing program.

Our other observations can be summarized as follows:

1. Two successful tests have been completed using the full-scale flexible bearings.

2. The Contractor is using the vacuum casting system used on the Minuteman program which has never had a motor rejected.

3. SRM cleaning and refurbishing procedures and methods are based on experience gained from USAF programs.

4. Personnel assigned to this program by the contractor have an average of 13 years of such experience.

5. The contractor and MSFC continue to actively study the

precautions necessary to assure full-time safe handling of the SRM's through every stage of the factory, delivery and installation activities.

B. RECOMMENDATIONS

Many important tests are to be conducted within the next few months, and should be the focus of attention by technical management. These tests include the first development firing of the SRM, the conduct of the "All-Up Engineering Integrated Verification Test," and many of the qualification tests. Our recommendations simply identify significant areas that need to be monitored during the test and analysis period.

1. The SRM, as in other areas of the SRB total assembly, are affected by the system aerothermodynamic loads. These latest data must be factored into the analysis and test as soon as practical to assure proper margins are maintained in the structures and other critical areas.

2. The nozzle bearing boot, although it has passed some tests, is not out of the woods as yet. There are concerns with regard to assuring that maximum material temperatures are not exceeded during the firing time and that no splits or openings occur allowing hot gas flow inside the bearing.

3. The Auxiliary Power Unit has experienced some "under performance" tests which require a reexamination and review to define the manner in which the performance and reliability of these important units can be upgraded.

4. The use of the RDX linear shaped charge to sever the aft end

of the SRM nozzle is a concern from the viewpoint of premature ignition. The temperatures and their duration would suggest that this item might be classed as a Category 1 hazard and treated accordingly.

5. The data returned from the first Orbital Flight Test mission, the first time the total SRB system will be tested as part of a total Shuttle system, will be crucial in defining the margins the SRB makes available to the total system. Since the SRB's must work each and every time, the flight test instrumentation, its location, etc. must be thoughtfully considered. Where transducers are placed into bosses they must be fail-safe. In other words the DFI must not be thought of as simply an "add-on" subsystem.

EXTERNAL TANK

A. OBSERVATIONS

The Panel has been reviewing such areas of the program as (1) the effects of new Shuttle system aerothermodynamic loads, (2) availability of hardware for the major Mated Vertical Ground Vibration Test and Main Propulsion Test, (3) manufacturing and welding problems, and (4) the assessment of ET hazards and their significance for the integrated Shuttle system.

Launch and ascent aerothermal analyses have been updated recently and there appears to be some effects on design and/or margins. For example, the LOX feedline bellows and bellows support, electrical cable trays and the forward LH_2 dome cap requires "beef-up" or material changes. The higher vibration levels affect instrumentation and vent valves. This may result in further differences between Main Propulsion Test Articles and Mated Vehicle Ground Vibration Test articles.

As for manufacturing there has been a changeover from the type of vertical welding fixtures used for the Saturn V S-I-C cases to a horizontal type. Practically all weld fixtures are now in use and this is a period of learning when adjustments and improvements will have to be made to assure the quality of the manufactured pieces. Among the problems that will have to be solved are balancing the hardware and proper motion control and achievement of welding gap consistency. The problems normal to the learning curve will be solved in time and the observance and control of all the variables will produce useable quality hardware.

There are additional fixtures and tooling to be introduced, tested and adjusted. During this process problems will occur. For instance, problems might be expected with the automatic TPS spray-on equipment and the process to obtain a relatively smooth outer-surface for the cylindrical portions of the tank as well as for both insulated end domes. The forward dome, exposed to higher dynamic pressure will be sensitive to surface discontinuities.

The Panel continues to follow the activities of the safety, reliability and quality assurance activities and their handling of major safety concerns. We have been giving particular attention to the handling of the risk from the presence of wiring in the LOX tank. Teflon insulated wire used for point level sensor assemblies is in direct contact with liquid and gaseous oxygen within the tank. Currently, the contractor is conducting development tests on these wires and other high temperature replacements to ascertain their properties under expected off-nominal (high) environments.

Also, the Panel has been following the handling of the hazard from ice building up on ET protuberances prior to launch and the effect of ice breaking off during launch and ascent when it could damage the Orbiter Thermal Protection system.

B. RECOMMENDATIONS

1. Consideration should be given to contingency planning or success assurance. The spray-on insulation is not expected to be machined over. What then would be done with an application that is

too thick for the spec because of a breakdown of a spray gun or blockage of the nozzles.

2. Additional management control should be considered for the ET-Orbiter interface. There is no plan for a mock-up or separation test with a complete hi-fidelity mock-up. Another concern that needs additional assessment is the possible damage to the Tank caused by the separation dynamic impact loads and subsequent endangering of the Orbiter.

3. Additional effort to determine the adequacy of the present ET/SRB attachment struts may be warranted if present struts do not attenuate pyro separation impact loads. There are no shock absorption devices on the ET-side of the interface.

RISK MANAGEMENT

A. OBSERVATIONS

The Panel has been following the methods used by program management to assess the risk level inherent in any endeavor as experimental and as demanding as the Shuttle System and commends the continuing attention being paid by the program to controlling these risks.

During this reporting period the Panel focused on such specific elements of the risk management system as risk assessment, configuration management and parts quality control. The risk assessment system provides a means for taking identified hazards, assessing their consequences and determining their disposition. Configuration management assures that the flight hardware as built and tested is as designed and therefore the design hazard analysis reflects the real hazards in the system. The review of parts control focused on the use of counterfeit electronic parts to assure they do not degrade the safety of the design.

The review of the risk assessment also considered the role and work of the Safety, Reliability and Quality Assurance Screening Committee in deciding what risks should be brought to management's attention. This led to the expansion of the committee to include the NASA Headquarters' Director of Safety, Reliability and Quality Assurance and a Panel member as an observer. This supports the group in a broader view of its responsibility and encourages a more effective voice in resolving risk and hazard problems.

At the Panel's suggestion the committee is auditing the handling of safety concerns not brought to management's attention because they are considered minor. The audit is done through the random selection of safety concerns which are not considered serious enough at that point in time to be placed in the open concern list. This permits a testing of the population of problems to see if any serious ones have been overlooked. The last sampling of the 500+ concerns consisted of twenty selected at random. The screening board found only one that was possibly close to becoming an open concern. The Safety, Reliability and Quality Assurance organization will in the next few weeks review all 500 concerns to see if any should be upgraded.

The procedures of the Safety, Reliability and Quality Assurance Screening Committee have been changed to include a meeting of the group two weeks prior to the first captive flight with a manned active Orbiter. Representatives of the project and program offices, support personnel, and engineering design group and others would be invited to participate in the pre-review. The purpose is to minimize the possibility of something having been missed that might bite the program later on and to minimize the chance of a surprise. In short, it amounts to a recheck of the risks and hazards in either system integration or design characteristics. The Panel encourages this effort.

The Panel became concerned about published reports which discussed the possible use of bogus parts in electronic equipment, and conducted a review of the steps taken to resolve this problem.

Tests have been run on "counterfeit" parts found in the load controllers. These parts indicate that the problem is not one of quality, but one of purchasing procedure or specification. If, indeed, "rejected" parts were relabeled, appropriate action against the vendor should be instituted.

The program's response is that the best method of assuring that component parts are adequate for their intended purposes on the Shuttle Program is to assure that all flight components are exposed to the expected flight environments for the expected mission times prior to the first approach and landing (FAL). These tests are required whether counterfeit or non-counterfeit parts are used; also, they will ensure that any unsuspected counterfeit parts that are in the vehicle will adequately meet the program requirements. If the results of investigative efforts to determine the source of parts relabeling are sufficient to make a case, appropriate action against that vendor will be instituted.

In addition to these specific reviews the Panel continued to monitor and counsel on the evolution of the technical assessment groups and the system for aggregate risk assessment.

The Panel encouraged the establishment of technical assessment groups at each manned flight center to contribute to the "check and balance" function in the risk management system. As noted in last year's report, these groups can either trouble-shoot pressing problems in terms of schedule impact, etc. or they can focus on identifying problems that are significant for the program's understanding of both specific risks and aggregate risk. Both roles are valuable but the

Panel favors the second one. It is, of course, important that these groups have the freedom to choose and pursue their own areas of investigation so their reports are in fact independent evaluations. The Panel has monitored the activities of the team at JSC and found that they appear to have this freedom and use it effectively to review critical areas and thus are making a significant contribution to the program.

There is general agreement that an appropriate statement of aggregate or total risk is a valuable senior management tool. A constant awareness provides incentives for accepting new ideas to diminish such risks and might encourage all who had systems responsibility to suggest means of coping with such hazards should they occur. Such a statement in the Panel's opinion would include the accepted risks and those risks being resolved.

The Panel has been working with the system for preparing aggregate risk since the Apollo days when it proposed the mission safety assessment documents to aid management decision making on those critical flights. This is the background for saying that while the concept of total risk is simple the task of defining and profiling aggregate risk is complex for a number of reasons. This past year senior program management has taken a fresh look at the systems and their own requirements for visibility and revised the system.

B. RECOMMENDATIONS

1. The Panel recognizes the accomplishments of both senior program and Safety, Reliability and Quality Assurance management and their

continuing efforts to define and determine aggregate risk in a manner most useful to senior management. The current system provides a great deal of risk information, but the challenge is to assure it is a useful tool for the decision-makers on the Shuttle program. Mission hazard analyses were made on prior manned space missions to show those safety concerns which would constrain a mission until resolved. In this way they were providing the aggregate risk based on the best available information which was examined from objective and subjective viewpoints. The ALT project safety assessment report has essentially done this as noted by this statement "The JSC Safety Division considers the aggregate risk acceptable, based on the assessment of safety concerns to date, considering the accepted risks and the actions being accomplished to resolve open items." Perhaps what is needed are detailed presentations to management by project and sub-system engineers as well as safety, reliability and quality assurance engineers so that statements made in mission safety analyses allows management to selectively review the background for specific Shuttle flights.

2. As noted the technical assessment group at JSC is off to a good start and shows that it can make a significant contribution to risk management. Since their continued effectiveness now depends upon the level of support and direct interest by senior program management the Panel makes a point of recommending such personal attention.

3. The effectiveness of configuration management depends upon the implementation of the system as described to the Panel. Therefore, the Panel recommends that audits of the operation of the system con-

tinue to be brought to management's attention during this period of development testing, checkout to assure the "as-built" and "as-tested" reflects the "as-designed" systems. This applies to both hardware and software.

4. The Panel agrees with the program investigation that the quality of small electronic parts in the Shuttle is adequate, and would suggest that in the procurement of this class of parts that reliance be placed on the performance specification rather than brand name.

APPENDIX A

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
CY 1976 ANNUAL COMPREHENSIVE REVIEW
AEROSPACE SAFETY ADVISORY PANEL

The Panel held its annual meeting on July 23, 1976 in Washington to present the observations and recommendations in its Annual Report before the Administrator and Deputy Administrator with members of the congressional staffs and aerospace media in attendance. One result of this approach was that the Aerospace Daily, which is widely read in the aerospace community, gave prominent coverage to the Panel's assessment.

The volumes of the Annual Report to the NASA Administrator include:

Volume I - Observations and Conclusions (111 pages)
Volume II - Summary of Information Developed in the Panel's Fact-Finding Activities (308 pages)

The Panel, through its inspection trips, requires program management at both NASA and contractor levels to review and explicitly explain their technical management systems and decision making process, the basis for confidence in crew safety, and the rationale for risks that have had to be accepted. This approach reinforces decision making that minimizes crew risk. It also serves to assure problems are worked early and at the lowest appropriate management level. The Panel reports to the Administrator and Congress and provides them independent assessment and substantial information that aids them in their oversight responsibility. These reports keep before senior manned flight management's attention issues critical to crew safety. And because these reports are timely and public, they add to the public's informed understanding and the development of appropriate criteria of public accountability.

The following paragraphs illustrate the value of the Panel's approach and some of their contributions to agency policy formulation, program planning, decision making, and the accomplishment of program objectives more efficiently and economically. Substantially more detail is in the attachment containing the Panel's recommendations on Shuttle and the program's response.

The Committee on Science and Technology of the U.S. House of Representatives is one of the committees exercising oversight of the Panel. They noted in their "Space Shuttle 1977 Status Report" that:

> "The annual report of the Aerospace Safety Advisory Panel (ASAP), a group appointed by the Administrator

of NASA for independent review of NASA programs, concentrated its attention on the Space Shuttle program in 1975-76. This effort, published by NASA in June, 1976, noted a number of critical areas and recommended actions to be taken to strengthen the program.

In making this (the Committee) current review, the ASAP comments were noted to aid in assessing the posture of the Space Shuttle Program."

An example of how the Committee used the Panel's assessment in their own investigation and deliberation is the first issue discussed in the Issues Section on Page 3 of the Committee's Report:

"Of particular note were the ASAP comments on the reliance on the ability of the Space Shuttle system during launch to lift the Orbiter vehicle to sufficient altitude to successfully abort the flight in the operational portion of the program, if necessary. (During the development flights, two ejection seats and a ground controlled destruct system will be available during the launch phase of each flight.) The Panel's review indicated that, assuming removal of the destruct system, the two ejection seats and the Shuttle crew enlarged, prudent steps in testing and evaluation of the essential elements of the launch phase of the operation were being satisfactorily undertaken and accomplished by NASA. This issue was further pursued in this review with the finding that, although an intensive program from design through development flights is taking place for the major orbiter systems, the intensity of such effort can not be assumed, but must be reexamined regularly."

Policy Formulation. The Panel provides management an assessment of the impact of its policies so they can be revised as appropriate. Policy on a development program is often under evaluation reflecting the challenges of the program. For example, the Panel proposed a policy that would institute assessment groups at NASA Shuttle Program Management Center to review and evaluate critical areas of the program. This policy was adopted and these centers are now effectively underway and have made significant contribution as check and balance and/or toubleshooting groups to assure critical areas are properly worked. In monitoring such areas as integration of the main propulsion system, the Panel found that the newly established Chief Engineer at MSFC for the Main Propulsion System was not a member of the integration panel (e.g., Systems Integration Review Panel) activities at JSC. The Panel believes that he should have direct participation and membership in the Systems Integration Review Panel activities, as well as be a part of the approval cycle for Level II and III documents pertaining to his area of responsibility to assure effective program integration.

Program Planning and Accomplishment of Program Objectives More Effectively. One of the key roles of the Panel is to alert management to upcoming challenges so they will be able to give them the appropriate attention and resources. In its assessment of the hydraulic system in the June 1975 Annual Report (Volume I, Page 5), the Panel suggested "that management review once again the following areas to assure there is an adequate basis for confidence for crew safety in the use of single actuator on the Orbiter elevons." The more detailed assessment (Volume II, Pages 69-71) raised questions about the hydraulic system. Subsequent test results lent support to the need for this review and redesigns have been instituted for the systems that will fly on the Orbiter in CY 1977 and more extensive changes for the system that will be used on orbital flights.

Program planning and accomplishment of objectives can be more efficient if past experience from related programs is effectively used. Therefore, the Panel suggested and the program agreed that personnel with experience in lifting body flights be asked to participate in the Shuttle training aircraft program to train Orbiter crews.

Agency Management Decision Making. One of the continuing objectives of decision making is to reduce risks whenever and wherever possible. This means management needs timely visibility into risks that are being accepted so they can assess whether the decision process is sound. It also means that management needs to have a timely reminder of significant risks so that (a) current decisions or tradeoffs to minimize a current risk in one area does not increase the risk in another area, and (b) as new options to reduce previously accepted risks become apparent they are recognized and acted upon by management. Thus the Panel proposed and senior program management implemented a system of continuing and regular reviews for senior space flight management by the reliability, quality and safety personnel who act as a check and balance on the program.

Another area that the Panel has reviewed is the system for accepting "minor risks" by working level personnel since these are not part of senior management's review. The objective is to assure that these risks have been properly assessed and dispositioned. Thus a Panel proposed that the risk screening board audit by sampling the handling of minor risks. This approach was adopted and a Panel member and the Director of Reliability, Quality and Safety monitor the activities of the Board.

Achievement of Economies in the Program. The Panel through its questioning and assessments aids management in identifying those priorities that are most significant for crew safety and mission success. This aids them in allocating resources to appropriate priorities and thus helps assure the most economical use of resources.

It is not feasible to expect such information from other advisory groups because they are not principally concerned with crew safety. To compare the Panel with line and staff organizations, its membership is composed of senior executives (a) experienced in managing large development programs and risk control, (b) sensitive to the requirements of public accountability, and (c) capable of providing a fresh look and independent judgment needed in a "check and balance" function.

The Panel's budget is $142,000. The increase over prior years is principally because the members rate of compensation was increased by Congress to bring it up to the level paid other NASA consultants. This was an act of equity by Congress since the Panel members rate had not changed in the eight years of the Panel's existence and they had been accepting a rate of compensation about two-thirds of what other consultants were. This had been recognized and accepted by the Panel but became an embarrassment when a NASA consultant was asked to join the Panel because of his expertise and had to accept a reduction in rate of compensation.

Panel members are selected principally in terms of (a) their operating and executive experience with development programs, (b) their experience with, and sensitivity to, the accountability requirements of senior public officials, and (c) their non-involvement in the program under review. All of the current members have a background in research and development management and have worked with government programs at senior levels of accountability.

The Panel was established by Congress in Public Law 90-67 and has been intimately involved in the oversight of the later Apollo program, Skylab, and the Apollo-Soyuz Test Project. Currently it is working on Shuttle and will have a considerable workload through the development and early operational phases. It reinforces management attention to crew safety and works with management at NASA and its contractors to identify and resolve the risks inherent in a development program. Through its reports it aids NASA senior management and Congress in their oversight roles and provides the public extensive data for an informed understanding of program development and crew safety. It is unique in the NASA management system because it offers the experience of senior executives reviewing both policy and operating activities with a fresh look and independence of judgment needed in a "check and balance" or oversight function.

The objective, or criterion for organizing the Panel's workload, is to assure that management for vehicle development and mission operations adequately provides for crew and ground safety. Therefore, given the current stage of vehicle development, the Panel will concentrate on detailed oversight of the design, manufacturing and ground test activities for Orbiter 1 and 2 and the associated elements and provide appropriate reports for program and agency management. Also, the Panel will provide detailed oversight as mission planning for the early test flights evolve. Then the Panel will focus on launch and mission preparations and provide mission readiness assessments to aid agency management in their decision making.

NASA's Response to Comments made in the Aerospace Safety Advisory Panel Annual Report on the Space Shuttle Program dated June, 1976

- **Page 3, Para. 1.I.A.**

Comment: There is no margin in the schedule to accommodate major perturbations.

Response: Space Shuttle schedules have been developed to provide the proper balance concerning the amount of schedule time that could serve as contingency periods to accommodate development problems. Current Space Shuttle schedules do allow for normal perturbations as have been experienced in some instances to date with no impact to the overall schedule. To maintain large blocks of contingency time would be costly and inefficient. The Shuttle test program is designed to serve as verification of results obtained by other means (e.g., math modelling) so that any major problems will be identified early in the program.

- Page 5, Para. 1.II.A.1

Comment: Senior management will need to monitor: 1) the ability to meet minimum requirements where there are further reductions or changes in the major test program.

Response: Our review process insures that senior management is informed on major test program status and changes. This includes periodic reviews with the Program Director and Associate Administrator for Space Flight, and the establishment of ad hoc teams when special reviews are felt to be warranted (e.g., Space Shuttle acoustics testing, structural testing). The Management Council is also apprised of significant issues and used as a review forum for programmatic changes. Finally major test status and requirement changes are reviewed with the Administrator.

- Page 6, Para. 1.II.A.3

Comment: Senior management will need to monitor the realism of plans and schedules for the remaining tests where there are significant problems so that decisions can be made early rather than under schedule pressure.

Response: The Shuttle management reviews schedules and program progress on a continuing basis in order to judge their realism and to identify areas where increased attention may be required. We will continue to monitor this activity closely.

- Page 6, Para.1.II.B.1

  Comment: An area that warrants review now is the data required from ALT to support a flight readiness decision on the first orbital flights and therefore the current mission planning to obtain these data.

  Response: Careful management attention has been applied to (1) identification of the data required from ALT to support a flight readiness decision for the first orbital flights and (2) the ALT flight planning required to obtain these data. This attention is evident in numerous program documents. Volume III, Flight Operations, of JSC 07700, Program Definition and Requirements, relates the ALT objectives to the verification of capability for orbital flight. Space Shuttle Program Directives 5A, Flight Test Requirements, and 34, Mission Evaluation Requirements, are in effect to establish requirements for cross exchange of data. Further, ALT Flight Test Requirements (FTRs) have been developed to state logically the ALT data required to lift specific constraints against the ALT and OFT programs. The implementation of these directives in mission planning will continue to receive full management attention.

- Page 6, Para.1.II.B.2

  Comment: An area that warrants review now is the aggregate risk inherent in the "first flight" plan to assure it remains at an acceptable level.

  Response: ALT flight operations planning is under constant programmatic review. The risks associated with an individual flight are assessed to a large degree by the Flight Techniques Panel and reviewed by the Flight Crew Safety Panel, the Flight Test Program Panel, the Flight Operations Panel, and the Operations Integration Review and Range Safety Management processes. In particular, the Flight Crew Safety Panel will review all flight test safety issues on a regular basis to include the "first flight" risks. Further, "first flight" plan verifications will be accomplished using the Orbiter aeroflight simulator and the Shuttle Training Aircraft.

- Page 6, Para.1.II.B.3

  Comment: The basis for confidence that the structural capability of the 747 tail section will not be overloaded during tailcone off flights and that vibrations will not exceed crew tolerance.

  Response: Based on extensive wind tunnel test and analysis by Boeing and Rockwell International, it has been established that the structural capability of the 747 tail section will not be exceeded during tailcone off flights. The situation with regard to 747 crew tolerance is not conclusive. To conclusively establish the acceptability of full length tailcone off flights, it is planned to conduct precursor mated tailcone off taxi and flight tests. The results from these tests will be utilized in making a final decision on whether to conduct the full length tailcone off flights. Safety will be a paramount consideration in the decision.

- Page 6, Para. 1.II.B.4

  Comment: The test requirements and plans to give confidence that the landing gear will deploy and lock as required.

  Response: Ground tests of Orbiter landing gear deployment will be conducted under simulated flight conditions. In addition to ground tests, it is planned to conduct a deployment test during landing high speed rollout of the mated 747/Orbiter. The results of the ground and flight tests will be utilized to verify proper Orbiter landing gear deploy and lock prior to Orbiter free flight.

- Page 6, Para. 1.II.B.5

  Comment: An area that warrants review now is the plan to have adequate GSE at the proper place to support the ALT program.

  Response: All of the GSE required for ALT has been identified and design is approximately 98% complete. As of mid-August, 1976, there are no anticipated problems associated with having ALT GSE in place on time.

- Page 6, Para. 1.II.B.6

  Comment: The flight software requirements warrant review so there is an identical flight profile for autoland and manual modes.

  Response: ALT software requirements for autoland and the manual control modes have been established so that the pilot and commander will be able to fly the same trajectory as autoland (within the limits of human error). Flight plans are being prepared for compatible trajectories for both the outer $12^{\circ}/13^{\circ}$ and inner 1.5° glide slopes.

- Page 7, Para. 1.II.B.7

  Comment: An area that warrants review now is the provision to allow the crew to adjust the gain of the control system.

  Response: The proposal for pilot control of Flight Control System (FCS) gain was disapproved following detailed management review at the ALT Critical Design Review. The rationale for this decision is discussed in detail in our response to the ASAP suggestion that this proposal be further reviewed (see our response to paragraph 8.0, III. C. of the ASAP Report).

- Page 7, Para. 1.III.A.

  Comment: Give attention to the effectiveness of recent changes in the avionics management approach and the need for a software expert in the Technical Assessment Office as an independent advisor and check and balance.

  Response: The need to augment the Technical Assessment Office with software expertise has been known by management. As soon as qualified personnel can be found they will be added to the staff.

- Page 7, Para. 1.III.B.

  Comment: The management system to assure that contingency abort analyses are given the proper priority now so that changes, particularly, in the software, are being made while there is still the capability for changes.

  Response: The Ascent and Entry Working Group established by the Flight Operations Panel (FOP) provides a focal point for abort analyses. The review and implementation of contingency abort analysis findings are now an active function of the FOP and Operations Integration Review process.

- Page 7, Para. 1.III.C.

  Comment: Give attention to the total or integrated management plan to assure SRB reliability.

  Response: An SRB R,Q&A plan (SE-020-005-2H) has been baselined at level III which constitutes an overall plan of the requirements and controls to ensure high SRB reliability. The overall management system, although the prime responsibility of the Project Office has been designed to ensure that all critical failure modes/hazards and their effects are identified, reviewed and their impact assessed continuously at all program levels.

Above and beyond the normal major milestone reviews, additional activities and controls have been implemented as follows: A special intercenter S,R&QA Panel with appropriate subpanels has been created, joint surveys at all levels are being conducted, CIL's are being baselined to ensure management attention and approval of disposition actions/controls and an overall system level failure reporting and tracking system implemented.

- Page 8, Para. 1.IV.A.

Comment: The selection of a material and its methods of application for the external insulation, so that the program gets the flight performance it needs.

Response: Based on recently completed cryogenic tests, as well as flammability resistance and wind tunnel tests at AEDC the program has baselined CPR-488 compound as the new SOFI for the external tank. Methods of application of this material is the same as that used for the previously used compound (CPR 421).

- Page 8, Para. 1.IV.B.

Comment: Safeguards to protect auxiliary power unit with sea water exposure.

Response: The design requirements for the APU requires the component to have the capability of 20 uses after sea water exposure. As indicated in the ASAP report, we have been very successful in our sea water tests in flushing out the catalytic bed and refiring the gas generator successfully. We are still in the process of conducting sea water immersion tests of the APU and will use the results of these tests to make any required changes to assure compliance with design requirements. Some of the results of the test indicate differences in torque requirements and sealant requirements to prevent water from entering the gear box.

- Page 8, Para. 1.IV.C.1.

Comment: Follow closely the provisions to assure that TPS installation procedures and tools will maintain the required gap and step between tiles and to avoid the problem of an early tripping of the boundary layer.

Response: We agree that this is an area requiring diligent attention and plans and progress are continuously reviewed.

Rockwell and Lockheed, in a parallel effort, are evaluating two simplified approaches for installing TPS tile arrays. These investigations are expected to be completed in September, 1976, and the solution is expected to assure acceptable step and gap control.

Validity of the stringent criteria currently used is subject to reassessment but the final proof will be determined during the early flights, where the trajectories will be tailored to provide adequate margins.

- Page 9, Para. 1.IV.C.2.

Comment: Follow closely the provision to adequately protect vehicle openings during entry with insulation while assuring this insulation will not obstruct the operation of doors.

Response: A minimum of the doors are required to operate prior to reentry. The payload bay doors, vents, umbilical doors and aero sensors are exceptions. Of these, the payload bay doors and vents are located in relatively protected areas and the seal on the payload bay door, which was found to lose its flexibility when cold, is being changed to a design not affected by orbital temperatures. The umbilical doors actuate after ET separation and provisions have been made to cycle the doors and latches independently for trouble shooting on orbit. The seals selected should not be vulnerable to effects of temperature encountered. The landing gear doors and others are closed and sealed prior to launch and no physical change is anticipated in the material which would compromise operation.

- Page 15, Para. 2.II.A.3.

Comment: The staff of engineers in the systems engineering office may need to be increased. Management regularly should review the staffing of the systems engineering office to assure that its capability is appropriate for its responsibilities.

Response: Agree. Some upward adjustments have been made in the staffing of the systems engineering office. More people could be used productively in engineering and integration.

- Page 15, Para. 2.II.A.4

Comment: Most of the directives have to do with responsibilities for monitoring and evaluating Space Shuttle progress rather than specifying how the daily work gets done or how the daily integration decisions are made. Some do not clearly define responsibilities.

Response: The Systems Engineering Office is an organizational element under the Systems Integration Manager and a conventional management relationship exists. Instructions to the technical organizations outside the program office, however, may take different forms depending upon the nature of the direction and the associated impact, but are typically from within the chain of the Level II PRCB, the Systems Integration Review (SIR), or the Technical Manager/Technical Panel area. Responsibilities of each are covered by program directives and need to be considered collectively in defining relationships. For the example cited, daily integration effort is performed by the responsible NASA/contractor organization, as coordinated within the framework of the technical manager/panel structure and under the guidance of the Systems Engineering Office. Issues that need a broader review by nature of the interfaces or technical considerations are brought to the SIR, which is chaired by the Systems Integration Manager, for resolution. Those issues that involve requirement changes, cost or schedule impact, or substantial differences in technical options, are submitted to the Program Manager's Level II PRCB for decision and direction.

- Page 16, Para. 1.II.A.5.

Comment: Work on this (system engineering) plan has been delayed further. If the plan is not to be available in a timely fashion, the management will have to assure that the basic need that required such a document is met in another way.

Response: The system engineering plan consists of engineering master schedules and narrative sections detailing the working process of the responsible technical organizations. The heart of the plan is the schedule of input-output milestone commitments for the systems engineering/integration effort across the program. A conscious decision was made to concentrate on completing the milestone schedules as early as possible and allow the narratives to be developed as resources permit. The schedules have been released and in use since December, 1975. Since that time, improvements in detail definition have been made and updates are periodically incorporated in the master schedules. A System Integration Manager's Review and a Program Manager's Integration Review was instituted to provide for timely discussion of integration and resource issues that come out of the scheduling activity. Most of the narrative sections of the plan have now been completed and the remainder are in review. This delay has not affected the overall purpose for which the plans were intended.

- Page 17, Para. 2.II.A.7.

  Comment: Newly established chief engineer at MSFC for the Main Propulsion System was not a member of the Systems Integration Review Panel (SIR) at JSC. The panel believes that he should have direct participation and membership in the Systems Integration Rewiew Panel activities, as well as be a part of the approval cycle for Level II and III documents.

  Response: MSFC wrote a letter to JSC (12 November 1975) requesting that Mr. Charles Wood (Chief Eng. at MSFC for the Main Propulsion System) be added as a member of the SIR. JSC answered that the organization concept of the SIR was developed within the context of having a key Level II participant representing each functional area. Mr. Richard Ferguson, of JSC, was designated "Technical Manager for Integrated Propulsion and Fluids" for the area of interest to Mr. Wood. As such, Mr. Ferguson is available to coordinate with Mr. Wood relative to appropriate MSFC inputs to the SIR. In addition, Mr. Wood's name has been included for SIR meetings, announcements, minutes, etc. As such, Mr. Wood has direct input to Mr. Ferguson and the SIR panel for activities pertaining to the Main Propulsion System. Mr. Wood has the same relationship to the SIR panel as Mr. J. R. Thompson, MSFC SSME Project Manager, that is, direct participation in SIR panel activities in his area of interest.

- Page 18, Para. 2.II.B.1. and 2.

  Comment: 1. The Panel favors the role of identifying problems so the assessment groups can cover more areas of the program. 2. The Panel suggests that priority be given to safety issues rather than non-safety issues that may seem more pressing.

  Response: The assessment groups operate under broad charters and in general, identify, review, and evaluate rather than work a resolution to a problem. Problem solving is the responsibility of the inline organizations. The establishment of priorities is an internal process and reflects the considered judgment of the individual group and particular Center emphasis. Safety issues demand high priority but we would not want to exclude non-safety issues. Periodic reporting to the Program Director and Management Council provides a mechanism for reordering priorities if it is judged desirable.

- Page 20, Para. 2.II.C.1.

Comment: The explosion of a solid rocket booster, a main engine, the external tank, or a reaction control system in all likelihood cause the loss of an orbiter. Thus, all possible measures must be taken to prevent such an occurrence or to provide warning so that such an explosion could be prevented.

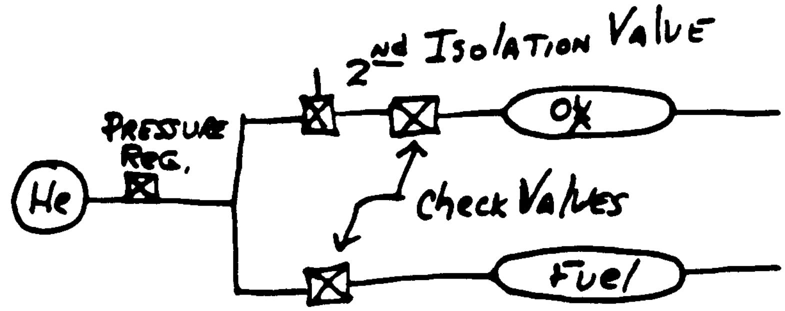
SSME Response: The Hawkins team was chartered to conduct an overall assessment of the Space Shuttle system. Out of this review came a separate "Engine Margin Review" whose objective was to "Reassess the SSME Structural Design". This assessment and structural audit was completed and reported on to the Hawkins Committee as well as to top NASA officials. Any additional reviews should start with reviewing the results of the Hawkins Team and the SSME Margin Review.

In addition, the Critical Design Review (CDR) will be held in September, 1976, which will assess the maturity of the SSME through a review of the design and testing results.

SRB Response: Plans are being implemented which identifies the approaches used, control methods, and procedures to ensure proper quality controls. These plans include identification of all failure modes, effects of these modes, hazard analysis, sneak circuit analyses and other risk assessments that could have a potential failure mode. The results of all these analyses are tracked with a continual assessment of program risks.

In addition to conducting assessment of potential risks to the SRB, specific requirements are imposed on the design to minimize failure modes. For example, these include using proven propellants used in previous solid motor programs, adding extra insulation to prevent the possibility of case burntthrough, and a well defined development and qualification test program which includes 7 motor firings.

OMS Response: The OMS subsystem manager and design personnel met with the ASAP people at the beginning of the OMS POD development effort and adopted the following design/operational features for the OMS design to accommodate all "known" safety requirements: (a) A fire wall is designed into the pod to separate the propellant tanks from the engine proper - it is not a blast wall, however, (b) a second isolation valve was installed in the OX tanks pressurant line between the regulator and the OX tank down stream of the "Tee" junction, which also supplies GN_2 to the fuel tank.



(c) The OX and fuel fill and drain valves are located on opposite sides of the vehicle (i.e., fill fuel from Rt. POD only and fill OX from Lt. POD only); (d) Shuttle pilots will have caution and warning lights on propulsion panel for identification of low pressure conditions in any of the fluid or pneumatic components of the OMS.

RCS Response: (a) The RCS plumbing and tankage is designed to no-fail limits of structural stresses. (b) RCS - GSE will have vapor detection sniffer capability for personnel safety (pre and post launch). (c) RCS plumbing will be leak checked pre and post launch. (d) Filling and draining criteria same as OMS.

- Page 20, Para. 2.II.C.2.

Comment: SRB or External Tank separation.

Response: The signals which arm and fire the "pyrotechnic" devices for the solids are dual redundant and the pyros are dual redundant. There are no known software contingency techniques to deal with the very remote problem of the failure of the solids to separate.

- Page 20, Para. 2.II.C.3

Comment: In the early flights there will be no Shuttle to perform rescue services, so effort should be made to minimize contingencies which might cause rescue to be needed. These include doors (payload bay doors, or umbilical door) which cannot be closed prior to reentry or the failure of the external tank to separate.

Response: The Space Shuttle is not designed to be dependent upon a rescue vehicle as a contingency backup. Crew safety requirements are the same as for previous programs where no rescue capability existed. Payload bay doors, for example, must be closed prior to reentry. The doors cannot be adequately verified as a system, prior to flight, because of the one "g" environment. Reliability will depend on simple, straight forward design which is amenable to analysis, and component testing. On any flight during which the doors will be opened, EVA capability will be provided, together with the necessary tools, etc. to permit manual closure of the doors by an EVA crewman.

- Page 21, Para. 2.II.C.4.

  Comment: Suggested that input and output devices and mechanisms be reviewed to doubly assure no "hard-overs" can exist.

  Response: The solids and the main engine gimbal systems are controlled by four port force-sum actuators. The system is being designed to tolerate two consecutive failures. In the remote case of a main "engine out" problem the failed engine will be gimballed in a fail-safe position such that the remaining two can be gimballed through their full authority of ± 10.5 degrees pitch and ± 8.5 degrees yaw. Input-Output devices and mechanisms for controlling the engine gimball's are under constant analyses and reviews.

- Page 21, Para. 2.II.C.5

  Comment: Adequacy of test and APU system design should be reviewed.

  Response: JSC indicated the APU is currently under safety and operational review and will continue to be so until all SSME gimbal and other hydraulic system functions are satisfied.

  A turbine wheel scatter shield has been designed into the turbine housing assembly to preclude a category 1 failure from an exploding turbine wheel.

- Page 21, Para. 2.II.C.6

  Comment: Loss of pressure in the cabin appears to be a singular and important hazard. There are two cabin air supply systems and three fuel cells which provide cabin air pressure and conditioning. The system must operate for the entire mission and total failure would be fatal. It is suggested that a concentrated review take place seeking once again the strong confirmation that there is a remote enough risk to take. A third air supply system might be feasible and valuable.

Response: We agree that the loss of cabin pressure is a critical and important hazard. There are two general categories of failures which could result in the loss of cabin pressure. One is the loss of pressure by external leaks; the other, by failure of the gas distribution and control system itself. An ancillary high pressure oxygen tank is provided for emergency backup. In the event of excessive external leakage, it will provide an 8 psig cabin pressure for a leak aperature equivalent to a .45 dia. hole for 165 minutes. An incident of such a leak is considered to be remote.

The primary mode of oxygen supply is from the fuel cell power reactant tanks. The nitrogen is stored in four high pressure vessels. Many of the systems components are identical to those of the Skylab which functioned perfectly for 171 days. Other redundant functions and hardware have been incorporated into the Orbiter, such as two stage pressure regulation, crossover manifolds, isolation values and manual controls. Failure mode and effects analyses have identified the most critical hazards and certification/ qualification plans have been baselined. We believe the addition of a third air supply would result in unnecessary cost, weight and complexity. We feel the continuing attention to the development and qualification of our present baseline will result in low risk to crew safety and mission success.

- Page 22, Para. 2. II. C. 7

Comment: Reevaluate Total System

Response: The controls and the APU systems are three parallel systems. Two APU systems are required to share the load.

- Page 22, Para. 2. II. C. 8

Comment: "Destruct" decisions for operational flight are needed.

Response: Decisions regarding employment of a flight termination system during the STS operational time period will not be made for sometime. In the next two years, the joint NASA USAF Range Safety Ad Hoc Committee will be exploring the risk-benefit considerations of planned operations. The involuntary risk must be maintained at a level acceptable to the public and at the same time bear a reasonable relationship to the voluntary risk accepted by flight personnel. We do not expect that decisions in this area will be confirmed until the OFT series is completed.

- Page 23, Para. 2. II. C.

  Comment: A similar detail review should be made of the crossover capability which exists on the control system to maintain hydraulic pressure in the event of APU failure with specific focus on the adequacy of maintaining hydraulic pressure in the main engine control valve system. If an APU shuts down there will be an automatic shutdown of that engine being served.

  Response: In the event of an APU failure, crossover capability exists to maintain hydraulic pressure in the SSME TVC, elevon actuators and wheel brakes. While crossover capability does not exist for SSME propellant control (due to cost, schedule and weight considerations), mission safety is not compromised. An APU failure would result in the shutdown of one SSME which would result in a safe intact abort case.

- Page 24, Para. 2. III. A.

  Comment: "Comprehensive review of integrating groups operations should be conducted regularly to insure responsiveness to program needs."

  Response: Agree. The integration activity in support of program requirements is highlighted through reviews with the Program Director, Associate Administrator for Space Flight, and selected Management Council topics. Special technical reviews are held in areas where support is critical, and, resource adjustments are made if required. The system integration organization and working relationships are well established but changes are made in panel structure and assignments as improvements are needed.

- Page 24, Para. 2. III. C. and D.

  Comment: C. Individuals at the systems integration level at JSC and at Rockwell's Space Division should be given appropriate management responsibility, authority and resources for contingency analysis and planning.

  D. Analysis and evaluation of vehicle capability for off-design cases should be done now, rather than later when necessary changes would be prohibitively costly. Staffing needed for this effort should be provided.

  Response: Most of the vehicle analysis for off-design/contingency capability has been delayed in deference to design/analysis effort in support of the Critical Design Review (CDR). This is an acceptable approach since no major hardware changes are anticipated to provide for contingency capability. Minor changes could be incorporated after the CDR.