TESTS TO SUPPORT SYSTEM IMPROVEMENT PROGRAMS

As noted in the introduction, it is suggested that a system improvement program be initiated almost immediately, not only for the purpose of improving the reliability performance of the shuttle system, but also to remove some of the risks that are now acceptable for first orbital flights but which should not be accepted for the eventual operational mode of the shuttle. Included in such design investigations should be:

a. A new concept or substantially improved APU system, including adequate margins of fuel capacity and high confidence of mechanical containment in the event of major failures in the rotating elements.

b. A thorough reevaluation of the necessity for nozzle skirt removal on the solid rocket boosters.

c. A complete reassessment of the necessity of nozzle vector control on the solids. One of the most complex systems with the least impact on the total shuttle performance is the current concept for moving the nozzles on the solid boosters. If a system could be devised that would permit fixed, or simply programmed, nozzles on the solid rocket boosters,a major simplification would have been achieved. Weight saving would be apparent and a substantial reduction in risk would result. Removing the APUs from the solid rockets, removing the vector control system from the rocket nozzles,and removing the necessity for hooking the solid rockets up to the basic control system all would be major improvements. This investigation should include a thorough assessment of the assumptions underlying the requirements for solid nozzle vectoring.

d. Whatever the results of "c" above, it would appear that a parallel or backup program would be desirable aimed at removing the APUs from the solid propellant boosters. The first flights should contain adequate instrumentation to confirm the dynamic characteristics of the total system in sufficient detail so that a redesign is possible utilizing added APUs within the main shuttle vehicle and removing them from the boosters. Even this would be a major simplification and would augment the total APU reliability by putting more than three APUs in the orbiter.

e. Also included in the system improvement program should be a consistent evaluation of all of the systems within the shuttle and the Orbiter to obtain at least "three engine, fail operational" capabilities for all essential systems. Prime efforts should be focused on (1) the APU where "fail operational" safety may require more than three APUs; (2) a new concept of elevon control system (implicit is the suggestion that multiple or tandem pistons are thought to be essential); (3) a completely new approach to the rudder speed brake and trim flap controls to remove from all of these systems any single point total failure elements; (4) a revised concept for main engine nozzle direction control to assure that full thrust to full duration can be achieved even if failure occurs in the nozzle direction control system; (5) a dual or triple source of voltage for solid rocket booster holddown releases; (6) a complete assessment of the interdependence of the backup control system to determine that failures in other parts of the system will not jeopardize the backup; particular attention should be paid to adjacent pin shorts; and (7) whatever is required, the APU should be modified so that shutdown and restart can be done without any time-consuming restraints, and its overall reliability improved so that it is on a par with the mechanisms which it is driving.

CONCLUSION

In planning for the future operational mode of the shuttle system, it should be recognized that the attention and the pilot and support expertise available for the first shuttle flights will not, and should not, be assumed to be present once the system is in its operational mode. Thus, the inherent reliability and invulnerability to failures of the shuttle system and the Orbiter must be substantially enhanced before truly operational status can be achieved. The system modifications just enumerated are only a few of the most obvious. The program management should mount a major assessment program for all systems similar to the evaluation recently done by McDonnell Douglas Corporation for the control system. The attitude of the program management should be one of extreme conservatism for operational safety. Development instrumentation and design investigation should now be concentrated in the risk removal area, even accepting some loss in payload performance to achieve the ultimate operational reliability.

SPACE TRANSPORTATION SYSTEM-PAYLOADS
(Domestic and Foreign)

Howard K. Nason

Payloads are an inherent part of the Space Transportation System and their status has matured to the point where safety issues concerning them could be addressed by the Panel during the past year. (A summary of the sites visited and subject matters discussed is included in Appendix B.) Two major items of interest at this time are the Spacelab with associated pallets and payloads and the Tele-operator Retrieval System (Skylab Mission). Of secondary interest has been the experiment and industrial payloads, both in the United States and those in Europe integrated by the Spacelab payload.

The Skylab reboost/deorbit mission is scheduled to be conducted on the second Shuttle mission some three to four months after the initial manned orbital mission. Our task focused on management's approach to this mission as regards to safety. Two premises have been made: conduct the mission as early as possible to achieve the greatest probability of successfully rendezvousing with the orbiting Skylab; and, if at all possible, attempt to boost the Skylab into a higher orbit to prolong its useful life. Based on our review to date the current program, both hardware and operations, appears to be moving in an orderly manner to meet the September 1979 delivery date. Hazard identification/elimination and reduction are being provided by design, and where this has not been possible, safety and warning devices along with operational constraints are being used. The spring ejection system has been designed and will be tested; stimulation devices for crew training will be in use soon;

the Johnson Space Center Flight Operations Panel is examining what measures can be taken on the first shuttle flight to support the Skylab reboost mission; and Systems Hazard Analyses and the Safety Compliance Data Package are being updated as required to account for a maturing program. Contingency plans should be made so they support the final decision-making which will be made, most likely, after the first shuttle manned orbital flight. In view of the special hazards involved with the relatively large quantities of fuel aboard, this program will be followed especially closely during 1979.

The European Space Agency has made substantial progress during this past year, the first year the Panel has had the opportunity to review this program. We focused on two specific areas of interest: (1) the management of the Spacelab/Pallet/Payload Integration program as it applies to operational safety and product reliability; and (2) the specific implementation of product assurance and safety programs with emphasis on technical aspects of the program. Three questions were in our minds during our participation in Spacelab activities: (1) The degree of "technical conscience" possessed by the program. In other words, do people throughout the organization feel that they have a responsibility to call to management's attention any concerns they may have, and do they believe that their concerns will be heard and acted upon? (2) Are lessons learned from other programs and within the program and are they applied? (3) What attention is being paid to the sum total of all the "accepted risks," and is there a "feed-back" system to assure such technical and management attention?

The program, at all levels, recognizes that time is growing short and to meet the delivery schedules will require continued technical and administrative visibility, timely and orderly exercise of prime contractor control, and enhanced software development and system engineering actions. All of this to conduct integrated tests and qualification testing on both the Engineering Model and Flight Units over the next ten months. Current major technical problems at this stage of the program must be resolved on a "systems basis" in order to minimize their impact on the current hardware, software and operational modes. Examples of this include the resolution of the airlock flange deformation without infringing on experiment volumes, unavailability of freon-21 as a coolant, environmental control and life support system thermal control, completion of the ncessary software programs for both test and operations. The many interfaces between payloads and the Spacelab and pallets need to be strengthened to eliminate conflicts of requirements at a later date. A more pressing need is to complete the technical (design/operational) baseline for the spacelab and pallets to assure that configuration control is maintained now and at the time of delivery of the hardware/software to NASA at Kennedy Space Center.

The European Space Agency and its contractors have put together a dedicated and knowledgeable product assurance organization which appears to receive full support of management. However, resource limitations necessitate prioritizing of product assurance efforts and this has been done well without unduly compromising safety and reliability. It does lead to accomplishment of workload in a serial fashion, and this makes the documentation lag, in some cases, somewhat restrictive.

It is recommended that a "walk-through" of the Spacelab and pallets be made by a highly experienced, non-spacelab group to assure that everything that can be done has been done to achieve a safe system. The walk-through has been an integral part of NASA's manned programs and most of NASA's research aircraft programs. This group might consist of six or seven people (perhaps one each from Johnson Space Center, Marshall Space Flight Center, Kennedy Space Center, Headquarters and several from the European Space Agency.

Within NASA there is a growing organization to handle the Space Transportation System "users," and specific attention has been paid to the safety aspects of such operations. A series of NASA documents from Headquarters and Johnson have been issued to cover policy, requirements and implementation for payload safety. Overall the intent is to minimize requirements to allow for the widest possible space transportation system. A large percentage of the requirements are to be met by the experimenters themselves with support from NASA as required. To fulfill the responsibility for payload integration and safety, the Shuttle Payloads Integration and Development Program Office conducts safety reviews with all organizations involved in the development of designated payloads. The funding to meet such an activity is included within the user's fee paid at the time a flight assignment is given. Additionally, there is a signed DOD/NASA agreement on safety certification of Defense Department payloads, which establishes agency roles and responsibilities. Subsequent agreements will be established covering payload ground and flight operations. It is important that organizational roles and responsibilities be fully defined prior to the first real payload mission, to assure that both operational and safety aspects of the flight have received due attention from the payload organizations. An example of this is the Johnson Space Center Management Instruction #11524, dated August 12, 1977, covering the "Space Transportation System Payload Safety Review Panel."

Ames has a wealth of experience with the management of payloads, as a result of their program of high-altitude experimental flights, and also have conducted simulations of Spacelab missions. It is urged that the entire system take full advantage of this resource.

In summary, the current schedule for the Skylab mission is such that reboost becomes problematical.

The Spacelab program is now into its integration and test phase, with delivery of the Engineering Module to Kennedy scheduled in 1979. This will require dedicated effort over the next months to assure the Spacelab system meets the necessary requirements.

Integration (system engineering) and full vehicle testing are critical at this time to meeting such goals.

The Space Transportation System payload appears to be in good shape with Johnson, Marshall, Goddard and Headquarters working together with Kennedy to assure that, through a standardized approach, safety requirements will be documented, tailored to meet the user's capability and needs, thereby opening the payload opportunities to the greatest number of commercial, governmental, university projects.

CONTROL OF HUMAN ERROR

Dr. Charles D. Harrington

The system for assuring that hardware as manufactured will be in accordance with drawings and specifications has been studied. Concentration has appropriately been at the Space Division of Rockwell International with some emphasis in the way it is applied to major subcontractors. The system of control and inspection remains essentially as it has been for some time and as it has been previously reported by the Aerospace Safety Advisory Panel.

The following factors are useful to management in assessing manufacturing performance.

1. Quality Trends: Assess Production Operations' performance relative to making defect-free hardware.
2. Manufacturing Verify Trend: Assess Production Operations' performance on evaluating the acceptability of their work.
3. Material Review Trends: Assess Production Operations' level of material review actions relative to cause of nonconformance and nature of disposition.
4. Inspection Detection: Assess inspection performance on detecting defects.
5. Corrective Action Trends: Assess status of Open, Initiated, Closed, and duration of Open Corrective Actions.
6. Defense Contracting Audit Service Inspection Trends: Assess nature and number of defects detected by the inspectors.

Items 1 and 2 are perhaps the most important of these in tracking human error.

The information systems have the capacity to detect changes in the level of performance for each of the items measured. The sensitivity of the instrument varies: for the Quality Trend report the lowest level of assessment is the department, whereas for the Manufacturing Verify report the lowest level is the individiual Production Operation stamp holder. They can also identify by part number, by defect type, and by cause of defect all nonconformances written on vehicle hardware and GSE at Downey, Palmdale, and all Material Review actions whether at Space Divison or any supplier. All Material Review information is available on-line and the nonconformances within 12 hours, and reports can be made in almost any format desired. The information systems in general cannot identify the individual mechanic who caused or contributed to the defect since many individuals may have worked on a specific part or sub-assembly. It should be pointed out that this refers to the "Assurance Management System" only. Supervisory inspection of individual workmen is used to detect poor performance, and additional training and/or replacement is used when indicated.

Production Quality Performance is presented in graphical and numerical form to show the performance of the Manufacturing Verification System. The performance is shown in the form of a percentage of defects found out of those which should have been caught by the manufacturing production inspection. This assumes that any defects missed at the inspection are subsequently caught by Quality Assurance or by the Defense Contracting Audit Service. This percentage generally runs in the high nineties, with some exceptions where a specific type of problem has caused many defects to go unnoticed at the manufacturing verification level. The dip in the period ending August 12 was caused mainly by the fact that a number of back-shells on electrical connectors were not tightened sufficiently, so that they became loosened and were subsequently detected by Quality Assurance.

The data discussed are for the Space Division of Rockwell International. Similar controls are imposed by Rockwell International on major subcontractors and they in turn are required to extend such controls to their subs as appropriate. It has not yet been possible for the Panel to investigate how well the system has been working at subcontractors, but this will be in the program for the coming year.

The hardware assessment summary is a system which has been put into operation during the current year. Quality Audit teams, in addition to reviewing the compliance with paperwork requirements, are inspecting critical manufacturing steps and hardware to understand better where defects in hardware or processing could occur and to understand the precautions which must be taken to minimize the likelihood of defective parts being produced. Unfortunately, due to lack of funding, this program was interrupted from May to September, but is now back in operation. The subcontractors to be so audited have been identified, but much work remains to be done before the Flight Readiness Review next August.

The Panel was represented at an audit at MOOG and was impressed with the thoroughness of the actual hardware examination.

This hardware assessment appears to be a good advance in the control of human error at the man-material interface.

As a specific example of what can be done to assure that hardware actually is in conformance with specifications, we examined the handling of the Wire Harness problem. This problem is the validation of the wiring after either initial buildup or rework. A team was selected and resulted in a computerized complete continuity test of the harnesses after each rework and included high potential testing. This confirmed the insulation, quality and functional routing of the wires. The physical quality of the work was checked by visual inspection.

The solution of this wire harness problem is an example of what can be done to estabish actual hardware configuration as against the design and prints. In some hardware cases it will be very difficult to establish test procedures which will duplicate all conditions which the hardware may experience in flight.

In summary, the development of primary inspection closer to the work (the Manufacturing Verification System) and the expansion of Hardware Assessment are positive steps toward reducing the likelihood of hardware as actually produced deviating from the drawings and specifications. During the coming year the Panel will follow the progress of these procedures with particular attention to the application throughout the subcontractor system.

PROPULSION SYSTEM

Dr. Seymour C. Himmel

Since our last meeting significant progress has been made in the development of the propulsion system for the shuttle. The SSME, the SRB and the External Tank are showing many of the signs that characterize maturing hardware. This progress was not achieved without problems or difficulty. When problems were encountered, they were attacked both vigorously and competently. Solutions to the difficulties have been devised and, thus far, testing has verified their adequacy.

External Tank

The External Tank is well into its test program and has progressed satisfactorily. It has supported the Main Propulsion Test very well. Changes in thermal loads and ice protection requirements have required extending the area covered with insulation so that now almost all the tank surface is insulated. The resulting weight increase detracts from the shuttle payload capability and this growth will probably have to be counterbalanced by a weight reduction program in the future.

The many manufacturing process controls required for the proper fabrication of the tank have gone through their growing pains. The need for strict adherence to the prescribed procedures is well recognized and steps have been taken to ensure compliance.

There have been two problems of consequence during the testing so far, one in the gaseous hydrogen diffuser and the other in the liquid oxygen tank ogive. The cause of the failure of the hydrogen diffuser has been determined and a design modification enbodying a material change should be sufficient to preclude further difficulty. The oxygen tank ogive buckle problem was corrected by requiring pressurization during servicing.

All told, the tank is doing quite well and should support the shuttle schedule (9-79) well.

Solid Rocket Booster

The Solid Rocket Booster has progressed well this past year. Quick look data from the recent firing of DM-3 looked quite good with ballistic performance, action time and thrust rise rates very close to predictions. The specific impulse from these early data was slightly better than requirement and in line with that achieved in the earlier firings. The case and the remaining insulation looked quite good. The determination of whether or not the modifications made to insulation and inhibitor geometries prior to the test achieved the desired improvements in performance must await detailed physical examination.

Process controls for casting have been improved and the casting equipment has been brought up to standards. The recovery system difficulties have been corrected as have other minor problems in the other subsystems. Handling problems are being brought under control.

The Booster development and qualification program should be able to support the shuttle per plan.

Space Shuttle Main Engine

The SSME development is, of course, the most challenging of the propulsion system programs. The many problems that have beset the development appear to be on their way to resolution. Most of the design changes selected have been incorporated into the test hardware and, for the most part, they have performed well in test.

The turbomachinery, the source of most of the SSME problems, is beginning to show signs of maturity. The high pressure oxygen turbopump bearings are holding up, and the high pressure fuel turbopump turbine blades are showing improved endurance now that the dampers have been improved and the excitation forces reduced. With the operability of the machinery enhanced, more attention can be focused on the performance enhancement of these machines. Progress is being made in this area too.

The combustion system continues to perform well and the fine tuning of the injector pattern appears to have reduced the severity of the local overheating that had been experienced earlier this year. The addition of velocity profile straighteners in the injector gas entrance ducts has apparently reduced or eliminated the injector liquid oxygen post fatigue problem.

The controller has completed, successfully, its grueling vibration qualification test and has performed very well in the engine test program. Software development is on schedule and the programs "fit" the controller.

The engines supported the first phase of the Main Propulsion Test quite well and no significant problems have arisen. Perhaps the more important achievements have been the full duration runs at rated power level, the 5000 plus seconds on engine 0005 and the almost 300 seconds near or at 102 percent rated power level. The heat exchanger operation has been verified in hot firing and fuel flow testing has been initiated. All of these accomplishments attest to the growing maturity of the main engine.

Of major import is the fact that decisions concerning the configuration and performance and test requirements for the main engines for the first manned flight have been made. The hardware currently in test is rapidly approaching the selected configuration. The design and test requirement decisions made are satisfactory for these flights and do not in any way compromise safety.

For operational flights further modifications will have to be incorporated into the engine with changes to provide lifetime and performance predominating. In addition, any consequences of operating at full power level will have to be accommodated.

All told, the main engine program appears to have "turned the corner" and I would anticipate that rapid progress toward achieving preliminary flight certification status will be made. I would expect that from time to time we will experience some hardware failure incidents as we have in the past. I believe that now these will probably not be caused by fundamental design-type problems.

Such incidents will, of course, have schedule implications because of the limited supply of hardware. Nonetheless, barring a major incident or unforeseen problem, the schedule (9-79) should be achievable.

In summary, the propulsion system development programs are in much better shape than they were a year ago. The fixes needed have, for the most part, been incorporated and proven. Much major testing remains to be accomplished and this is the key to Preliminary Flight Certification. All told, I would tend to be optimistic about this system achieving its near term objectives on, or close to, schedule (9-79).

RISK ASSESSMENT

Frank C. Di Luzio

To assure the Aerospace Safety Advisory Panel that the Safety, Reliability and Quality Assurance System mandated by NHB 5300.4 (1D-1) August 1974 - a summary of NHB 1700.1 NASA Safety Manual Vol. 1, NHB 5300.A (1A) and NHB 5300.4 (1B) - was effective and was being adhered to by NASA Centers and their contractors, the Panel conducted a systematic evaluation and review through a series of meetings, briefings, and walk-throughs at Johnson Space Center, Kennedy Space Center, and the Rockwell Safety Support organization (Space Division/Rockwell), Boeing, and TRW on Software Hazard Analysis.

There may appear to be duplication in several of the sub-panel reports or in reports prepared by individual Panel members, concerning areas of their expertise or areas of specific assignments, and this evaluation of the NASA Quality Assurance.

This is primarily due to the fact that quality assurance is an overall function at all levels of the Shuttle operations - as an example, the report on product Quality Assurance and related human factors deals with the Quality Assurance function, the human and/or organizational elements involved, while the risk assessment evaluation concerns itself with measuring the success of risk identification and elimination on the end product. In brief, the first measures performance, coordination, and supervision of people. The second, the effects of this attention on the final products or its elements.

The Panel was interested not only in the question of adherence to the procedures mandated by NASA, but was also interested in the effectiveness, character and climate of the several interfacings between the tier contractors involved. The contractors interface with NASA Centers and between the NASA Centers themselves.

In the opinion of the Panel, this review was necessary due to the great degree of coordination and cooperation needed to insure that no item was lost in the sequential process involved, and that information, evaluation, comments, and concerns flowed freely throughout the total organization, including NASA Headquarters, Centers and Shuttle Program contractor personnel.

The Review was a step-by-step approach starting with Johnson Space Center Quality Assurance operation as the Shuttle Hazard Identification and resolution was administered by Johnson Space Center at level 11 and on the Orbiter at level 111. The Rockwell support activity was then reviewed, and finally, a review of the Kennedy Space Center planning and organizational structure to manage and coordinate the acceptance, movement, assembly checkout and launch of the Shuttle. Kennedy Space Center presented an excellent opportunity to look into the results of all the preceding Quality Assurance programs.

All systems and sub-systems, complete with their Quality Assurance history, flow into the Kennedy Space Center for processing checkout and launch, using the computer-controlled Launch Processing System. Generally, the Kennedy personnel and their supporting contractors have seen, and are familiar with the characteristics of the hardware as they have participated in prior Quality Assurance reviews conducted by the designers and producers of the systems and sub-systems. There is a great deal of inter-play and participation by both NASA and contractor personnel with reviews conducted by lower tier contractors and contractors above, who integrate the components, sub-systems and systems into progressive configurations leading to final assemble.

The second phase of the Panel's Quality Assurance Reviews was to look into the purpose, function, and effectiveness of both formal and informal special reviews by study groups or task forces. These include the formal Senior Safety Review Board, Screening Boards, Orbiter Project Manager, and Space Shuttle Program Manager, formal briefings and the Headquarters-initiated Hawkins Committee, Crew Safety Panel, Safety System Sub-Panel, Operational Readiness Inspection for Sites, internal Rockwell reviews, Yardley formal and informal reviews, and various technical panels considering specific items such as the hydraulic system.

These task forces, panels, or technical reviews are extremely useful, if not overdone, and do not unnecessarily tie up Center personnel nor divert Center Management attention from their internal problems. Such activity appropriately created and staffed with competent knowledgeable people, can focus outside talent and provide a new look at the problem. This activity further concentrates the attention of NASA top Centers and Headquarters personnel on the problems and renews the drive of the total NASA organization for effective Quality Assurance procedures. Repetition and time have a way of dulling the awareness and concerns for a good and effective Quality Assurance function.

The Kennedy Space Center session included a review of the planning for OFT-1 Shuttle Processing Orbiter Landing Facility and the Shuttle Processing Launch Pad, Handling and Stacking, Orbiter Processing Facilities, with particular attention to the handling of toxic and/or inflammable materials such as hydrazine ammonia, etc. A review was also made of the very preliminary draft of the Kennedy Space Center - OFT-1 Space Shuttle First Vertical Flight Assessment dated June 2, 1978.

Many other documents and procedures were reviewed, i.e., Shuttle Element Interface Reliability Desk Instructions, Hazard Analyses Sheets, Kennedy Space Center Safety Review of ground support equipment. Design and Ground Operations and the OFT-1 Ground Operations Review Document prepared for briefing of Deke Slayton on June 15-16, 1978, a very complete and helpful document. Finally, Mission Safety Assessment, Analytical Effort, Critical Events Sequence Selections, Integrated Shuttle Program Risk Management Schedule, and Mission Safety Assessment documents.

As a result of these reviews, the ASAP is of the opinion that the documentation, procedures and internal reviews have been and are effective in identifying, examining and resolving possible hazards and that the free flow of information on evaluation of the safety, reliability, maintainability and quality assurance among Engineering and Design, Manufacturing, Test, and Operational Sites is a significant factor contributing to an effective Quality Assurance process across the total NASA Shuttle System.

NASA Reliability and Quality Assurance publication NHB.5300 (1D-1) August 1974 requires that each contractor maintain a safety activity planned and developed in conjunction with other functions. The purpose is to insure that special emphasis is placed on how to assure identification, elimination and/or control of potential hazards which may lead to injury, loss of personnel and/or damage or loss of flight or ground hardware throughout the program cycle.

In addition, an Industrial Safety/Occupational Health and Safety Plan was to be incorporated or attached to each safety plan. The Panel has predominantly spent its time on the Space Shuttle Transportation System and little time in looking into the normal industrial safety problems. At Kennedy Space Center and at other Centers there are activities such as the handling of heavy loads in the Stacking Operations and the handling of toxic and inflammable materials in the fueling and refurbishing tasks. The Panel will spend some time in reviewing the status of industrial safety, and the application of federal and state laws and regulations to both government and contractor activities.

The last Kennedy Space Center session also concerned itself with the review of Kennedy relationships with both its local contractors and contractors serving other Centers, but who are involved with further processing, testing of hardware shipped to Kennedy Space Center from manufacturers and other Centers. The reason for this concern is that many of the contractors, thus engaged, are under contract to other Centers and perform many other tasks, i.e., manufacturing, design, test and quality evaluations. The implication of these diverse functions and multiple use of contractors, is that they may actually be at work at Kennedy processing, inspecting and testing equipment, sub-systems, and systems provided by their parent organization. This situation can be a plus because of the continuity contractors can provide and their familiarization with hardware design, manufacturing, and prior testing, is very helpful in the final stacking, assembling and testing at the Kennedy Space Center. NASA management awareness of the several roles performed by the contractor organizations and the awareness of the contractors' top management can go a long way to avoid a conflict. It is, however, something that should be monitored.

RECOMMENDATIONS

The ASAP is concerned whether the payloads and, in particular, the Space Laboratory being designed and built in Europe is, in fact, being designed and built in a manner consistent with the operational safety standards of NASA. Both the quality of the Space Laboratory and the coordination between NASA and the European agencies involved should be carefully monitored.

It is very important that European scientists involved be trained and be familiar with the limitations and procedures to be followed in space experiments. The Ames Research Laboratory simulation of flight conditions for experimentors who will use Space Lab is a step in the right direction and should be expanded.

Criteria for payload safety requirements and responsibilities have been drafted, but as payloads change, revisions of standards and procedures will have to be made. From a Quality Assurance point of view, the general philosophy that payload sponsors are responsible for their own payloads' safety and NASA is responsible for payload standards and their interface with the Shuttle and other payloads on the same flight, is sound. NASA should, however, know the contents of each payload to satisfy itself as to its safety in handling and flight, and particularly, in an abort situation.

The Panel suggests that NASA re-evaluate the staffing of the Kennedy Space Center Quality Assurance staff and support personnel. The present staffing may be sufficient to perform the Kennedy Space Center Shuttle Processing, etc., if the program develops no late, unforeseen problems.

If problems develop late in the stacking and preparation process, present staffing may not be enough. The slipping of launch date for OFT-1 obviously helps ease the current workload.

With reference to the NASA decision to use OFT-2 to deliver and attach a small engine to Skylab in order to control and boost Skylab into a safer orbit, it may be prudent to evaluate the results of OFT-1 before final commitment to that course. The problem is that unless the OFT-1 flight is planned to exercise all on-board systems and capability that may be required for the OFT-2 rendezvous and maneuvers to deliver and attach the engine to Skylab, an undue hazardous condition could be needlessly created. Stresses that may be experienced for the first time on the Shuttle during this OFT-2 event should not be a stage for any unknown hazards.

Finally, the Panel is happy with the openness, frankness and efforts of the NASA Centers' and Contractors' personnel during this review of the system-wide Quality Assurance procedures and their effectiveness. Marty Raines, Director, SR & QA Division of Johnson Space Center, and Charles Baker, Product Quality Office, Rockwell, and John Atkins of SR & QA Office, Kennedy Space Center, are due particular thanks for their efforts.

With reference to the NASA request to the Panel to evaluate and recommend a process to achieve a numerical value for an aggregate risk assessment, the Panel has to date been unable to determine any creditable method. We examined the Department of Defense process of risk evaluation, the original Atomic Energy Commission weapons risk evaluation and the current Department of Energy methods. All produce meaningful information, but no one has developed a generally accepted method to set numerical values for aggregate risk.

The very nature of safety determinations and the wide-spread confusion about the nature of safety decision would be dispelled if the very meaning of the term safety were clarified. Many experts will define safety as a judgment of the acceptability of risk, and risk in turn, as a measure of probability and severity of harm to humans, and/or complex costly technical systems. This definition contrasts sharply with simplistic dictionary definitions that have safe meaning "free from risk," because nothing can be absolutely free of risk, nothing can be abolutely safe. There are degrees of risk and, consequently, there are degrees of safety. The NASA Quality Assurance system, in its entirety, can only reasonably insure that the risks involved in the OFT-1 are not caused by human error or because of an oversight.

Note also that the above definition emphasizes the relativity and judgmental nature of the concept of safety. It implies that two very different activities are required for determining how risk-free the Shuttle really is. They are: measuring the risk, an objective but probabilistic pursuit and judging the acceptability of that risk, a matter of personal-political and social value judgment. As most risk acceptance is based on human judgment, it is impossible to place any numerical value to that judgment.

In closing,the ASAP believes that the Quality Assurance system is working well and is effective, particularly, with continued top management interest and support.

THERMAL PROTECTION SYSTEM

C. A. Syvertson

While considerable work remains to be done, the key technical problems associated with the Space Shuttle thermal protection appear to be sufficiently well in hand to permit the first orbital flight to be made with confidence. The remaining work comes in two major areas: one of these is manufacturing. While a significant part of the tiles and other materials have been manufactured and installed on Orbiter 102, some of the most difficult tasks of manufacturing and assembly remain. Most of the tile arrays have been attached to the lower surface of the Shuttle, however, there are a few panels in more complicated areas missing and, more significantly, there are a large number of close-out tiles which must be manufactured and attached individually before installation of the thermal protection system will be completed. Manufacturing output between June and November was only about three-fourths of that planned. In order to support a launch as early as September 28, 1979, an improvement in manufacturing output will be required, although some time might be gained by shipping the Shuttle to KSC without a complete system; limited installation of tiles could be completed at KSC.

The second area where considerable work remains is testing, especially that for certification of the materials. Some key development tests and a comprehensive series of certification tests must be completed before the first orbital flight. The certification tests necessitate a rigor in terms of identification of test specimens, documentation of materials and processes, and R&QA involvement that makes these tests significantly more difficult to complete than development tests. As a result of the rigorous requirements, difficulties are already being experienced in maintaining schedules.

All of the manufacturing, installation, and test activities associated with the thermal protection system must be highly successful in meeting current schedules if the September 28, 1979 launch date is to be met.

Beyond the first few Shuttle flights, emphasis should be placed on reducing the weight and cost of the thermal protection system and on minimizing and improving the ease of refurbishment between flights. In order to achieve these objectives, two things must be done. First, sufficient data must be obtained from the early flights to define accurately both the performance of the system and the environment it experiences during entry. These data are especially important since it is not possible to create the complete entry environment in ground-based tests or to estimate it with desired precision by theoretical analysis. While flight data systems, such as the Developmental Flight Instrumentation and Aerodynamic Coefficient Instrument package, will obtain some of the information required, other activities within the Orbiter Experiments Program, including remote infrared observations of the Shuttle during entry, will provide important added understanding.

Second, new thermal protection materials and systems should be explored with the objective of making the thermal protection system more compatible with the concept of an operational vehicle. Activities in these areas are underway and should continue to be given modest support. Some of the materials being studied are:

1. Fibrous Refractory Composite Insulation is a new form of Reusable Surface Insulation that provides increased strain to failure and strength by factors of two or greater, over current materials. It also has a significantly increased temperature capability. Arc-jet tests to quantify this will be performed in the near future. An additional benefit is that the coating is in compression whereas in the current material it is in tension--an undesirable state of stress for a ceramic in terms of damage resistance. This new material can be directly substituted for that now in use and should provide increased life and lower weight.

2. Advanced Flexible Reusable Surface Insulation is a silica-felt enclosed in glass, silica or AB-312 cloth and stitched in a blanket form. This material was developed as a substitute for low temperature insulation and those regions where the local temperature limits flexible insulation reuse. The advantages of advanced flexibility insulation over low temperature insulation are lower installed material cost by an estimated 2.4 million dollars per Orbiter, lower weight by 100-300 pounds, and significantly enhanced reuse since it is not rigid and brittle.

3. Black AB-312 cloth was developed by the 3-M Company under NASA sponsorship as a direct substitute for the current white AB-312 cloth used for gap fillers and thermal barrier seals. Two advantages of this development are higher thermal emittance

and reduced crystal grain growth. The increased emittance results in reduced temperature and, therefore, greater reuse of both the cloth and adjacent tiles. The inhibited grain growth will result in retaining flexibility at high temperatures and therefore greater reuse.

APPENDIX B

1978

PANEL MEETINGS

and

FACT-FINDING MEETINGS

1978 PANEL MEETINGS

January 17	Shuttle Critical Functions Review, Space Shuttle Main Engine	NASA Headquarters
February 22	Testimony before the Senate Subcommittee on Science, Technology and Space	U. S. Senate
April 13-14	Shuttle Thermal Protection System and Tile Manufacturing	Ames Research Cent Lockheed
June 13-14	Space Shuttle Main Engine	Rocketdyne
August 8-9	Shuttle Acceptance, Transport, Preparation for Launch. Associated Range Safety Operations	Kennedy Space Cent
October 11-12	Avionics, Shuttle Safety and Risk Analysis, Technical Assessments on Shuttle	Johnson Space Cent
November 30	Annual Meeting: Presentation by each Panel Member on his assessment of his area of responsibility	NASA Headquarters

1978 FACT-FINDING MEETINGS
by
Individual Panel Members

January 17	Ames Experience with Payloads and Mission Simulations	Ames Research Cente
January 19-20	Shuttle Crew Operations/Training	Johnson Space Cente
January 30-February 2	Shuttle Payloads, Propulsion Power, SSME	NASA Headquarters, National Academy of Engineering
January 31-February 2	Reliability, Quality Control, Human Errors, APU for Orbiter	Rockwell Internatio
February 2	Spacelab CDR Preparation	Marshall Space Flig Center
February 14-15	Rotor Systems Research Aircraft and Stall Spin Research Aircraft	Langely Research Center
February 23-March 8	Spacelab Critical Design Review, Payloads, Product Assurance	European Space Agen
March 28-30	Quiet Short-Haul Research Aircraft Engineering/Safety Review	ing
April 4-6/10	Spacelab Joint Working Group, STS Payloads Integration, USAF	Kennedy Space Cente Johnson Space Cente Space and Missile Systems Organiza
May 31-June 2	Shuttle Mission Operations, Crew Training and SS-1 Management	Johnson Space Cente
June 9	Auxiliary Power Units (APUs)	Sunstrand
June 15-16	Reliability, Safety and Quality Assurance at Primes and Subs on Orbiter Program	Rockwell Internatio

June 26-30	Hazard Identification, Risk Assessment, Shuttle Hazards Screening Board	Kennedy Space Center, Johnson Space Center
July 13, 1978	Telephone Participation on McDonnell-Douglas Critique of Shuttle Control System	Washington, D. C.
July 12-14	Launch Processing System and Range Safety for Shuttle	Kennedy Space Center Eastern Test Range
August 9	All Shuttle Projects and Payloads, Solid Rocket Booster, SSME and External Tank	Marshall Space Fligh Center
August 13-16	Particpation in Audit of Subcontract Building Critical Hardware (Actuators)	Moog Manufacturing C
August 28-29	Shuttle Hydraulic System Assessment	McDonnell-Douglas Corporation
September 11-12	Shuttle Avionics Software and Hardware	Johnson Space Center
September 27-28	Shuttle Flight Control System and its Validation	Johnson Space Center
October 5-16	Spacelab Product Assurance/Safety	European Space Agenc Spacelab Project Gro
October 30-November 1	"Fly-by-Wire" and Fault Tolerant Multi-Processors used in Aircraft and Orbiter Control Systems	Draper Laboratory
November 3	Spacelab Program	NASA Headquarters
November 27	Range Safety and High Performance Aircraft Control Characteristics Applied to Shuttle Orbiter	Space and Mission Systems Organizat