January 30, 2004
Volume 1, Revision 1.2

NASA's Implementation Plan for Space Shuttle Return to Flight and Beyond

A periodically updated document demonstrating our progress toward safe return to flight and implementation of the Columbia *Accident Investigation Board recommendations*

NASA's Implementation Plan for Space Shuttle Return to Flight and Beyond

A periodically updated document demonstrating our progress toward safe return to flight and implementation of the* Columbia *Accident Investigation Board recommendations

January 30, 2004
Volume 1, Revision 1.2

An electronic version of this implementation plan is available at www.nasa.gov

Revision 1.2 Summary
January 30, 2004

This revision to *NASA's Implementation Plan for Space Shuttle Return to Flight and Beyond* reflects our progress to date in responding to the recommendations and observations of the *Columbia* Accident Investigation Board (CAIB). This revision does not change the entire document, but only selected pages in the sections listed below. The changed pages can be inserted in place of the current pages of the Plan.

As we issue this revision, NASA is embarking on a new and exciting chapter in space exploration. The President's new vision for U.S. space exploration, "A Renewed Spirit of Discovery," calls for a sustained, achievable, and affordable human and robotic program to explore the solar system and beyond. The first necessary and critical step in achieving these ambitious goals is returning the Space Shuttle safely to flight.

As a result, our near-term mission for the Space Shuttle remains unchanged—to return the Shuttle to flight as soon as safely possible in order to complete assembly of the International Space Station (ISS). The Space Shuttle will be phased out with completion of ISS assembly, planned for the end of this decade. With the change in the planned service life of the Space Shuttle and a shift in Agency priorities, we will reassess our investment strategy to ensure safety and sustainability for the remainder of the Shuttle service life.

Future revisions of *NASA's Implementation Plan for Space Shuttle Return to Flight and Beyond* will reflect the role of the Space Shuttle defined in this new vision.

The following is a list of the sections affected by this Revision:

Response Summaries
CAIB Recommendations Implementation Schedule
Return to Flight Cost Summary
Part 1 – NASA's Response to the *Columbia* Accident Investigation Board's Recommendations
- 3.3-2 Orbiter Hardening [RTF]
- 3.3-1 Reinforced Carbon-Carbon Nondestructive Inspection [RTF]
- 3.3-4 Reinforced Carbon-Carbon Database
- 3.3-5 Minimizing Zinc Primer Leaching
- 3.8-1 Reinforced Carbon-Carbon Spares
- 4.2-3 Closeout Inspection [RTF]
- 4.2-5 Foreign Object Debris Processes [RTF]

Part 2 – Raising the Bar – Other Corrective Actions
- 2.1 – Space Shuttle Program Actions
- SSP-1 Quality Planning and Requirements Document/Government Mandated Inspection Points
- 2.2 – CAIB Observations
- O10.1-1 Public Risk Policy
- O10.4-1 KSC Quality Planning Requirements Document
- O10.10-1 External Tank Attach Ring

The following pages have been changed or added in this Revision 1.2:

Add Page

Revision 1.2 Summary page

Remove Pages	**Replace With Pages**
Title page (Nov. 20, 2003)	Title page (Jan. 30, 2004)
xix (Oct. 15, 2003) – xxxii (Sep. 8, 2003)	xix (Jan. 30, 2004) – xxxii (Jan. 30, 2004)
xxxiii (Oct. 15, 2003) – xxxvi (Oct. 15, 2003)	xxxiii (Jan. 30, 2004) – xxxvi (Oct. 15, 2003)
xxxvi-a (Nov. 20, 2003) – xxxvi-b (Nov. 20, 2003)	xxxvi-a (Jan. 30, 2004) – xxxvi-b (Jan. 30, 2004)
1-11 (Sep. 8, 2003) – 1-16 (Oct. 15, 2003)	1-11 (Jan. 30, 2004) – 1-16 (Jan. 30, 2004)
1-27 (Oct. 15, 2003) – 1-32 (Sep. 8, 2003)	1-27 (Jan. 30, 2004) – 1-32 (Sep. 8, 2003)
1-57 (Oct. 15, 2003)– 1-58 (Sep. 8, 2003)	1-57 (Jan. 30, 2004) – 1-58 (Sep. 8, 2003)
1-61 (Oct. 15, 2003) – 1-62 (Sep. 8, 2003)	1-61 (Jan. 30, 2004) – 1-62 (Sep. 8, 2003)
2-1 (Nov. 20, 2003) – 2-2 (Sep. 8, 2003)	2-1 (Jan. 30, 2004) – 2-2 (Jan. 30, 2004)
2-35 – 2-36 (Sep. 8, 2003)	2-35 (Jan. 30, 2004) – 2-36 (Jan. 30, 2004)
2-41 (Oct. 15, 2003) – 2-42 (Oct. 15, 2003)	2-41 (Jan. 30, 2004) – 2-42 (Jan. 30, 2004)
2-69 (Oct. 15, 2003) – 2-70 (Oct. 15, 2003)	2-69 (Jan. 30, 2004) – 2-70 (Jan. 30, 2004)
B-9 (Oct. 15, 2003) – B-12 (Sep. 8, 2003)	B-9 (Jan. 30, 2004) – B-12 (Sep. 8, 2003)

A black bar in the margin indicates a change.

Changes made in Revision 1.1, issued November 20, 2003, are described in the following summary.

Response Summaries

Part 1 – NASA's Responses to the Columbia *Accident Investigation Board's Recommendations*

The following section provides brief summaries of the NASA response to each CAIB recommendation in the order that they appear in the CAIB report. We must comply with those actions marked "RTF" before we return to flight. Additional detail on each response can be found in the following sections of this implementation plan. This is a preliminary plan that will be periodically updated. As we begin to implement these recommendations and continue our evaluation of the CAIB report, we will be able to respond more completely. Program milestones built on the CAIB recommendations will determine when we can return to safe flight.

3.2-1 Initiate an aggressive program to eliminate all External Tank Thermal Protection System debris-shedding at the source with particular emphasis on the region where the bipod struts attach to the External Tank. [RTF]

The immediate cause of the *Columbia* accident was debris shed by the External Tank during launch. As a result, we are focused on minimizing External Tank-generated debris, which may include ice, foam, and other materials. The Space Shuttle Program is assessing the entire External Tank Thermal Protection System design, examining potential ascent debris sources. Our work will focus primarily on the following areas:

- *Forward Bipod Ramp* – NASA has redesigned the ramp to eliminate the foam ramp and incorporate redundant heaters.
- *LO_2 Feedline Bellows (Ice)* – The baseline solution being pursued is a "drip lip" and drain concept. As a backup solution, development will continue on the purge system concept.
- *Protuberance Airload (PAL) Ramps* – Potential solutions are to verify the current design; replace the ramps with a more controlled foam application technique; or eliminate the ramps altogether.
- *LH_2/Intertank Flange Closeout* – Potential solutions are performing a localized gas purge; sealing the flow path from the intertank joint to the foam; improving Thermal Protection System closeout to prevent voids; and improving procedures to minimize post-manufacturing foam damage.
- *Foam Verification Reassessment* – NASA is reassessing the Thermal Protection System verification rationale and data for all processes for applying foam to the External Tank. NASA will ensure that at least two employees attend all final closeouts and critical hand-spraying procedures to ensure proper processing.
- *Nondestructive Inspection (NDI) of Foam* – NASA has initiated a long-term program to develop NDI techniques for foam for improved process verification.
- *Long-Term Activities* – As part of the Shuttle Service Life Extension activities, NASA is evaluating potential long-term changes in the External Tank design to continue our aggressive program to eliminate debris shedding at the source.

3.3-2 Initiate a program designed to increase the Orbiter's ability to sustain minor debris damage by measures such as improved impact-resistant Reinforced Carbon-Carbon and acreage tiles. This program should determine the actual impact resistance of current materials and the effect of likely debris strikes. [RTF]

NASA is defining potential redesigns that will harden the Space Shuttle against damage caused by debris impacts. In April 2003, NASA developed 17 redesign candidates. Eight near-term options were selected for further study. NASA is developing detailed feasibility assessments for each of these options.

NASA is also conducting foam impact tests on RCC and tile to determine their ability to withstand impacts and to build computer models that will accurately predict impact damage. Three full-scale impact tests of RCC were recently conducted at the Southwest Research Institute using exponential increases in the kinetic energy of the impacts. The first test used a foam projectile of 0.1 lb. mass at 700 ft/sec (fps), and the second test doubled the

kinetic energy of the initial test by using a 0.2 lb. projectile at 700 fps. Neither test resulted in damage to the RCC panel. The third test doubled the kinetic energy of the second test by using a 0.16 lb. projectile at 1167 fps. This test resulted in multiple through cracks and permanent deflections in the RCC panel.

3.3-1 Develop and implement a comprehensive inspection plan to determine the structural integrity of all Reinforced Carbon-Carbon system components. This inspection plan should take advantage of advanced nondestructive inspection technology. [RTF]

NASA is committed to clearing all RCC components and hardware by certified inspection techniques before return to flight. We have removed the OV-104 RCC nose cap, chin panel, and all wing leading edge components and returned them to the vendor for comprehensive nondestructive inspection (NDI). To date, the results compare favorably to data collected when the components were manufactured, indicating mass loss and coating degradation are within acceptable limits.

For the long term, the Space Shuttle Program is reviewing inspection criteria and advanced on- and off-vehicle NDI techniques for the Orbiter RCC system components. For instance, we have already introduced advanced off-vehicle flash thermography to inspect RCC components. Efforts to develop advanced on-vehicle NDI continue. We have identified and are pursuing five candidates with good potential for near-term deployment.

6.4-1 For missions to the International Space Station, develop a practicable capability to inspect and effect emergency repairs to the widest possible range of damage to the Thermal Protection System, including both tile and Reinforced Carbon-Carbon, taking advantage of the additional capabilities available when near to or docked at the International Space Station.

For non-Station missions, develop a comprehensive autonomous (independent of Station) inspection and repair capability to cover the widest possible range of damage scenarios.

Accomplish an on-orbit Thermal Protection System inspection, using appropriate assets and capabilities, early in all missions.

The ultimate objective should be a fully autonomous capability for all missions to address the possibility that an International Space Station mission fails to achieve the correct orbit, fails to dock successfully, or is damaged during or after docking. [RTF]

NASA's near-term Thermal Protection System risk mitigation plan includes eliminating critical debris-shedding from the External Tank; fielding improved ground-based and vehicle-based cameras for debris damage discovery; surveying the vehicle on orbit using the Space Shuttle and International Space Station remote manipulator system cameras; and using International Space Station crew observations during Shuttle approach and docking. Near-term corrective actions under development include extravehicular activities for tile and RCC repair. A combination of new capabilities in this area should help to ensure that we can detect any damage and react successfully should damage occur. NASA's long-term objective is to provide a fully autonomous Thermal Protection System repair capability for all Space Shuttle missions.

3.3-3 To the extent possible, increase the Orbiter's ability to successfully re-enter Earth's atmosphere with minor leading edge structural sub-system damage.

The Space Shuttle Program is evaluating the Orbiter's capability to enter the Earth's atmosphere with minor damage, taking into account design limitations. NASA will define minor and critical damage using RCC foam impact tests, arc jet tests, and wind tunnel tests; modify existing flight design while remaining within certification; and explore ways to expand the flight certification envelope. Additionally, we will evaluate trajectory design changes to provide additional thermal relief on the leading edge support system.

3.3-4 In order to understand the true material characteristics of Reinforced Carbon-Carbon components, develop a comprehensive database of flown Reinforced Carbon-Carbon material characteristics by destructive testing and evaluation.

The Space Shuttle Program is currently developing and implementing an RCC test plan to develop a comprehensive database of flown and nonflown RCC material characteristics. A multicenter team will continually update the test plan to assist with directing design upgrades, mission/life adjustments, and other critical concerns for the service life of the leading edge support system and RCC.

NASA will use the foam impact tests on RCC and tile to build computer models that will accurately predict impact damage.

3.3-5 Improve the maintenance of launch pad structures to minimize the leaching of zinc primer onto Reinforced Carbon-Carbon components.

Zinc-rich coatings are used to protect the launch pad structure against environmental corrosion. Before return to flight, the NASA Kennedy Space Center will enhance the launch pad structural maintenance program to reduce RCC zinc oxide exposure and prevent zinc-induced pinhole formation in the RCC. We are also pursuing enhanced inspection, structural maintenance, wash-down, enhanced physical protection, and sampling options.

3.8-1 Obtain sufficient spare Reinforced Carbon-Carbon panel assemblies and associated support components to ensure that decisions related to Reinforced Carbon-Carbon maintenance are made on the basis of component specifications, free of external pressures relating to schedules, costs, or other considerations.

The Space Shuttle Program will maintain one complete set of RCC panel assembly spares for flight use. We will also develop a prioritized list of additional spare panels that will be ordered after the initial four panels are delivered.

3.8-2 Develop, validate, and maintain physics-based computer models to evaluate Thermal Protection System damage from debris impacts. These tools should provide realistic and timely estimates of any impact damage from possible debris from any source that may ultimately impact the Orbiter. Establish impact damage thresholds that trigger responsive corrective action, such as on-orbit inspection and repair, when indicated.

Foam impact testing showed that existing computer models need to be improved. NASA will evaluate the adequacy of all preflight and in-flight analysis tools that provide assessments critical to mission safety and success and make all necessary improvements.

3.4-1 Upgrade the imaging system to be capable of providing a minimum of three useful views of the Space Shuttle from liftoff to at least Solid Rocket Booster separation, along any expected ascent azimuth. The operational status of these assets should be included in the Launch Commit Criteria for future launches. Consider using ships or aircraft to provide additional views of the Shuttle during ascent. [RTF]

NASA and the United States Air Force are working to improve the use of ground assets for viewing launch activities. To help ensure safe Space Shuttle missions, we are jointly evaluating various still and motion imagery capabilities, the best camera locations for both types of imagery, day and night coverage, live transmission and recorded imagery, and minimum weather requirements.

NASA is still deciding which combination of assets will be required for launch, but the selection criteria will ensure improved damage detection and engineering assessment capability. NASA has determined that STS-114 will be launched in daylight with a lighted External Tank separation. This will maximize our ability to obtain three useful camera views during ascent to allow us to pinpoint areas of engineering interest.

3.4-2 Provide a capability to obtain and downlink high-resolution images of the External Tank after it separates. [RTF]

To provide the capability to downlink images of the ET after separation to the MCC in Houston, NASA is assessing options for modifying the cameras in the Orbiter umbilical well. These images may be downlinked in real time or shortly after safe orbit is achieved, depending on which option is selected. Beginning with STS-114, and until these modifications are complete, the flight crew will use handheld digital still imagery to document the ET separation and downlink the images to the MCC.

3.4-3 Provide a capability to obtain and downlink high-resolution images of the underside of the Orbiter wing leading edge and forward section of both wings' Thermal Protection System. [RTF]

NASA will add a suite of ascent cameras in various locations on the Space Shuttle's External Tank (ET) and Solid Rocket Boosters (SRBs) to view selected areas of interest. For near-term return-to-flight, these cameras will supplement the on-orbit inspections that will provide the primary source of complete, high-resolution coverage needed to clear the Orbiter's Thermal Protection System of unacceptable damage. The ascent cameras will provide additional valuable engineering data on vehicle condition,

including confirmation of the performance of the ET modifications to reduce debris. For STS-114, a camera with downlink capability is being added to the ET to view portions of the Orbiter wing leading edge and underside tile acreage, and the modified ET bipod attachment fitting. A camera will also be added to each SRB to provide views of the ET intertank region. For subsequent missions, additional cameras will be mounted on the ET and the SRBs to provide multiple views of the ET and almost the entire Orbiter wing leading edge and underside, including critical landing gear door and umbilical door areas. For the long-term, NASA will evaluate upgrades to the on-vehicle ascent imaging and sensor suite that might make redundant some of the on-orbit inspections.

6.3-2 Modify the Memorandum of Agreement with the National Imagery and Mapping Agency (NIMA) to make the imaging of each Shuttle flight while on orbit a standard requirement. [RTF]

NASA did not use the full capabilities of the United States to assess the condition of the *Columbia* during STS-107. NASA has now concluded a Memorandum of Agreement with the National Imagery and Mapping Agency and has engaged other national agencies and assets to help us assess the condition of the Orbiter during launch, on orbit, and during entry. NASA has determined which personnel and positions require access to the national capabilities, and we are writing implementation procedures.

3.6-1 The Modular Auxiliary Data System instrumentation and sensor suite on each Orbiter should be maintained and updated to include current sensor and data acquisition technologies.

NASA agrees that the Modular Auxiliary Data System needs to be maintained until a new replacement concept is developed and implemented. The Space Shuttle Program is currently reviewing sensor requirements for various Orbiter subsystems, evaluating and updating sustainability requirements, investigating alternative manufacturers of the magnetic tape, and improving the procedures and process to lengthen the life of the Modular Auxiliary Data System recorder.

3.6-2 The Modular Auxiliary Data System should be redesigned to include engineering performance and vehicle health information and have the ability to be reconfigured during flight in order to allow certain data to be recorded, telemetered, or both, as needs change.

NASA is evaluating a replacement for the Modular Auxiliary Data System that will address system obsolescence and also provide additional capability. The Vehicle Health Monitoring System (VHMS) is a project within the Service Life Extension activities to replace the existing Modular Auxiliary Data System with an all-digital, industry-standard instrumentation system. VHMS will provide increased capability to enable easier sensor addition that will lead to significant improvements in monitoring vehicle health.

4.2-2 As part of the Shuttle Service Life Extension Program and potential 40-year service life, develop a state-of-the-art means to inspect all Orbiter wiring, including that which is inaccessible.

NASA is creating a roadmap for developing a state-of-the-art Shuttle wiring inspection capability. As a first step, we are collaborating with industry and other government agencies to find the most effective means to address these concerns.

4.2-1 Test and qualify the flight hardware bolt catchers. [RTF]

The External Tank is attached to the Solid Rocket Boosters (SRBs) at the forward skirt thrust fitting by the forward separation bolt. Approximately two minutes after launch, a pyrotechnic device is fired that breaks each forward separation bolt into two pieces, allowing the SRB to separate from the External Tank. The bolt catcher attached to the External Tank fitting retains half of the separation bolt while the other half of the bolt is retained within a cavity in the SRB forward skirt. The STS-107 investigation showed that the Bolt Catcher Assembly's factor of safety was approximately 1 instead of the required factor of safety of 1.4. We are redesigning the Bolt Catcher Assembly. Testing and qualification of the redesigned Bolt Catcher Assemblies and External Tank attachment bolts and inserts is in progress.

4.2-3 Require that at least two employees attend all final closeouts and intertank area hand-spraying procedures. [RTF]

The Space Shuttle Program has approved a general approach for External Tank Thermal Protection System certification; the Space Flight Leadership Council has in turn approved the approach for review by the Return to Flight Task Group. Material Processing Plans will be revised to require that, at a minimum, all ET critical hard-

ware processes be performed in the presence of two certified Production Operations employees. TPS verification activities are under way and specific applicable ET processing procedures are under review.

4.2-4 Require the Space Shuttle to be operated with the same degree of safety for micrometeoroid and orbital debris as the degree of safety calculated for the International Space Station. Change the micrometeoroid and orbital debris safety criteria from guidelines to requirements.

To improve Shuttle safety regarding micrometeoroid and orbital debris (MMOD), NASA is evaluating potential vehicle modifications, such as new impact debris sensors, next-generation tiles and toughened strain isolation pad materials, improved Reinforced Carbon-Carbon, and improved crew module aft bulkhead protection. Additionally, a study is under way to assess the advantages afforded by alternative docking locations on ISS as well as other ISS modifications that reduce the Orbiter's exposure to MMOD while docked to the ISS. Hypervelocity impact tests will continue; and BUMPER code, a computer simulation and modeling tool for MMOD, will be updated to support the risk reduction effort.

4.2-5 Kennedy Space Center Quality Assurance and United Space Alliance must return to the straightforward, industry-standard definition of "Foreign Object Debris," and eliminate any alternate or statistically deceptive definitions like "processing debris." [RTF]

NASA will implement a consistent definition of foreign object debris across all processing activities; current metrics to measure such debris will be improved; NASA will provide foreign object debris prevention surveillance throughout the entire processing timeline; and foreign object debris training will be updated and improved. A team of NASA and United Space Alliance employees was formed and has completed benchmarking industry and Department of Defense processing facilities.

6.2-1 Adopt and maintain a Shuttle flight schedule that is consistent with available resources. Although schedule deadlines are an important management tool, those deadlines must be regularly evaluated to ensure that any additional risk incurred to meet the schedule is recognized, understood, and acceptable. [RTF]

Our priorities will always be flying safely and accomplishing our missions successfully. We will fly only when the necessary milestones are achieved, and not be driven by planning schedules.

NASA will adopt and maintain a Shuttle flight schedule that is consistent with available resources. Schedule risk will be regularly assessed and unacceptable risk will be mitigated. NASA will develop a process for Shuttle launch schedules that incorporates all of the manifest constraints and allows adequate margin to accommodate a normalized amount of changes. This process will entail launch margin, cargo/logistics margin, and crew timeline margin. The Space Shuttle Program (SSP) will enhance and strengthen the existing risk management system that assesses technical, schedule, and programmatic risks. Additionally, the SSP will examine the risk management process that is currently used by the International Space Station. The data will be placed in the One NASA Management Information System so that the senior managers in the Space Flight Enterprise can virtually review schedule performance indicators and risk assessments on a real-time basis.

6.3-1 Implement an expanded training program in which the Mission Management Team faces potential crew and vehicle safety contingencies beyond launch and ascent. These contingencies should involve potential loss of Shuttle or crew, contain numerous uncertainties and unknowns, and require the Mission Management Team to assemble and interact with support organizations across NASA/Contractor lines and in various locations. [RTF]

The Flight Mission Management Team will be reorganized to improve communication, chain of command, and the team's ability to accurately assess the relative risks of options under consideration. A clear reporting path and formal processes will be established for the review of findings from ascent and on-orbit imagery analyses. In complying with this recommendation, this new Mission Management Team structure will be exercised during real-time simulations before return to flight. These simulations will bring together the flight crew, the flight control team, engineering staff, and the Mission Management Team in complex scenarios that teach better problem recognition and reaction skills. Additionally, postlaunch hardware inspections and ascent reconstruction will be implemented. A process will also be established to review and

address mission anomalies and to identify them to the Mission Management Team.

7.5-1 Establish an independent Technical Engineering Authority that is responsible for technical requirements and all waivers to them, and will build a disciplined, systematic approach to identifying, analyzing, and controlling hazards throughout the life cycle of the Shuttle System. The independent technical authority does the following as a minimum:

- **Develop and maintain technical standards for all Space Shuttle Program projects and elements**
- **Be the sole waiver-granting authority for all technical standards**
- **Conduct trend and risk analysis at the subsystem, system, and enterprise levels**
- **Own the failure mode, effects analysis and hazard reporting systems.**
- **Conduct integrated hazard analysis**
- **Decide what is and is not an anomalous event**
- **Independently verify launch readiness**
- **Approve the provisions of the recertification program called for in Recommendation R9.1-1**

The Technical Engineering Authority should be funded directly from NASA Headquarters and should have no connection to or responsibility for schedule or program cost.

7.5-2 NASA Headquarters Office of Safety and Mission Assurance should have direct line authority over the entire Space Shuttle Program safety organization and should be independently resourced.

9.1-1 Prepare a detailed plan for defining, establishing, transitioning, and implementing an independent Technical Engineering Authority, independent safety program, and a reorganized Space Shuttle Integration Office as described in R7.5-1, R7.5-2, and R7.5-3. In addition, NASA should submit annual reports to Congress, as part of the budget review process, on its implementation activities. [RTF]

This response applies to recommendations 7.5-1, 7.5-2, and 9.1-1. NASA is committed to putting in place the organizational structure and culture to operate the Shuttle Program safely and with technical excellence for years to come. NASA will take the appropriate time to adequately assess our options, understand the risks, and implement the needed change. Before return to flight, an interdisciplinary team will be formed to develop a detailed plan for defining, establishing, transitioning, and implementing the recommendations. The Office of Safety and Mission Assurance has been assigned as the focal point for this recommendation.

As a first step, NASA recently established the NASA Engineering and Safety Center (NESC) at Langley Research Center. The NESC will provide augmented engineering and safety assessments, and will be operational by October 1, 2003. The Headquarters Office of Safety and Mission Assurance will provide the NESC's budget and policy to assure independence.

7.5-3 Reorganize the Space Shuttle Integration Office to make it capable of integrating all elements of the Space Shuttle Program, including the Orbiter.

NASA has strengthened the role of the Shuttle Integration Office to make it capable of integrating all of the projects and elements of the Program, including the Orbiter Project. The new office, the Shuttle Engineering and Integration Office, reports directly to the Program Manager. The Integration Control Board has also been strengthened and membership has been expanded.

9.2-1 Prior to operating the Shuttle beyond 2010, develop and conduct a vehicle recertification at the material, component, subsystem, and system levels. Recertification requirements should be included in the Service Life Extension Program.

The mid-life certification of the Shuttle is a key element of NASA's Shuttle Service Life Extension work. Efforts to recertify the Shuttle began before the *Columbia* accident. In December 2002, the Space Shuttle Program Council tasked all Space Shuttle Program projects and elements to review their hardware qualification and verification requirements, and confirm that processing and operating conditions are consistent with the original hardware certification. This will be an ongoing process incorporated in the Shuttle Service Life Extension, as appropriate.

10.3-1 Develop an interim program of closeout photographs for all critical sub-systems that differ from engineering drawings. Digitize the closeout photograph system so that images are immediately available for on-orbit troubleshooting. [RTF]

NASA needs the capability to quickly retrieve accurate photos and images of critical Space Shuttle subsystems to support on-orbit troubleshooting and ground operations.

NASA will identify and acquire images of critical areas and details for capture in the digital image database. The images will be stored in a database from which they can be retrieved by cross-referencing to top-level drawings or vehicle zone locators. To improve the quality of broad-area closeout imaging, hardware changes may include advanced technology, such as 360° field-of-view cameras and high-definition photography.

10.3-2 Provide adequate resources for a long-term program to upgrade the Shuttle engineering drawing system including

- **Reviewing drawings for accuracy**
- **Converting all drawings to a computer-aided drafting system**
- **Incorporating engineering changes**

NASA will develop detailed plans and costs for upgrading the Shuttle engineering drawing system. Currently in the formulation phase, the work that remains to be completed includes assessing current design documentation and developing drawing conversion standards, concept of operations, system architecture, and procurement strategies. At the conclusion of this phase, the Digital Shuttle Project will present detailed plans and costs for upgrading the Shuttle engineering drawing system and seek authorization from the Space Shuttle Program to proceed with implementation.

Response Summaries

Part 2 – Raising the Bar – Other Corrective Actions

NASA has embraced the *Columbia* Accident Investigation Board (CAIB) report and will comply with its recommendations. We recognize that we must undertake a fundamental reevaluation of our Agency's culture and processes. To do this, we have begun an intensive, Agencywide effort to identify additional actions above and beyond the CAIB recommendations that will further improve our space flight program as we move toward a return to safe flight. The result of this ongoing effort is a set of internally generated actions that complements and builds upon the CAIB recommendations. These actions also begin to address several of the key observations included in the CAIB report. As we progress in our return to flight work, we will evaluate, address, and report on our response to the other observations. A list of the CAIB observations from Volume I of the CAIB report is included below.

In addition to the actions listed below, as a first step to improve our programs, NASA established the NASA Engineering and Safety Center (NESC) at Langley Research Center to provide an augmented, independent assessment capability. NESC will provide a centralized location for the management of independent, in-depth technical assessments supported by expert personnel and state-of-the-art tools. It will conduct tests to certify problem resolution, validate computer models, and provide independent trend analyses. The NESC is discussed in our response to CAIB Recommendation 7.5-1.

SSP-1 NASA should commission an assessment, independent of the Space Shuttle Program, of the Quality Planning and Requirements Document (QPRD) to determine the effectiveness of government mandatory inspection point (GMIP) criteria in assuring verification of critical functions before each Shuttle mission. The assessment should sample the existing GMIPs against the QPRD criteria and determine the adequacy of the GMIPs in meeting the criteria. Over the long term, NASA should periodically review the effectiveness of the QPRD inspection criteria against ground processing and flight experience to determine if GMIPs are effective in assuring safe flight operations.

NASA chartered an Independent Assessment Team (IAT) to evaluate the effectiveness of the SSP's government mandatory inspection point verification process for the Shuttle Processing Directorate at Kennedy Space Center and the External Tank Project at the Michoud Assembly Facility. In January 2004, the IAT released a report with findings, recommendations, and observations related to GMIP policy, processes, and workforce. The IAT's preliminary findings, recommendations, and observations were briefed to the Office of Safety and Mission Assurance and the Office of Space Flight, and the final IAT report has been provided to the Space Shuttle Program for implementation.

SSP-2 The Space Shuttle Program will evaluate relative public risk between landing opportunities that encompass all cross-ranges, each operational inclination, and each of the three primary landing sites.

NASA will evaluate the risk posed by Space Shuttle overflight during entry and landing. Controls such as ground track and landing site changes will be considered to manage the risk to persons and property, the flight crew, and the vehicle.

SSP-3 NASA will evaluate the feasibility of providing contingency life support on board the International Space Station (ISS) to stranded Shuttle crewmembers until repair or rescue can be affected.

NASA has developed an International Space Station (ISS) Contingency Shuttle Crew Support concept that could be used in an emergency to sustain a Space Shuttle crew on board the ISS until either the damaged Space Shuttle is repaired or the crew can be returned safely to Earth. NASA's preliminary feasibility study suggests that for the next Space Shuttle mission, should it be necessary, the Space Shuttle crew could be sustained on the ISS for a period of at least 86 days, which is sufficient time to rescue the crew with a second Space Shuttle.

SSP-4 NASA will validate that the controls are appropriate and implemented properly for "accepted risk" hazards and any other hazards, regardless of classification, that warrant review due to working group observations or fault-tree analysis.

Hazard analysis is the determination of potential sources of danger and recommended resolutions for the problems identified. Approval of acceptable risk hazards are those known risks that remain even after all available mitigation efforts are implemented. Approval of acceptable risk hazards is based on a judgment that the possible consequences and likelihood of occurrence are tolerable.

All SSP projects are performing an assessment of each accepted risk hazard report and any additional hazard reports indicated by the STS-107 accident investigation findings.

SSP-5 NASA will determine critical debris sources, transport mechanisms, and resulting impact areas. Based on the results of this assessment, we will recommend changes or redesigns which would reduce the debris risk. And NASA will review all program baseline debris requirements to ensure appropriateness and consistency.

NASA has embarked on a comprehensive effort to analyze, characterize, and reduce potential critical ascent debris sources. Eliminating all ascent debris large enough to inflict serious damage to the Shuttle is a priority for NASA.

SSP-6 All waivers, deviations, and exceptions to Space Shuttle Program requirements documentation will be reviewed for validity and acceptability before return to flight.

Since all waivers, deviations, and exceptions to Program requirements carry the potential for risk, the SSP is reviewing all of them for appropriateness. In addition, each project and element will identify and review in detail those critical items list waivers that have ascent debris as a consequence.

SSP-7 The Space Shuttle Program should consider NASA Accident Investigation Team (NAIT) working group findings, observations, and recommendations.

All NASA Accident Investigation Team technical working groups have an action to present their findings, observations, and recommendations to the Program Requirements Control Board (PRCB). Each project and element will disposition recommendations within their project to determine which should be return to flight actions. They will forward actions that require SSP or Agency implementation to the SSP PRCB for disposition.

SSP-8 NASA will identify Certification of Flight Readiness (CoFR) process changes, including Program milestone reviews, Flight Readiness Review (FRR), and prelaunch Mission Management Team processes to improve the system.

The certification of flight readiness (CoFR) is the process by which NASA ensures compliance with Program requirements and judges launch readiness. The CoFR process includes multiple reviews at progressively higher management levels, culminating with the Flight Readiness Review. Each organization that signs the CoFR, or that presents or prepares elements of the CoFR, has been assigned a PRCB action to conduct a thorough review of the CoFR process.

SSP-9 NASA will verify the validity and acceptability of failure mode and effects analyses (FMEAs) and critical items lists (CILs) that warrant review based on fault tree analysis or working group observations.

In preparation for return to flight, NASA is developing a plan to evaluate the effectiveness of the Shuttle failure mode and effects analyses (FMEAs) and critical items lists (CILs) processes. This review will validate the documented controls associated with the SSP critical items lists. The SSP will identify FMEAs and CILs that need to be revalidated based on their criticality and overall contribution to Space Shuttle risk. NASA will also assess STS-107 investigation findings and observations that affect FMEAs and CIL documentation and controls.

SSP-10 NASA will review Program, project, and element contingency action plans and update them based on the *Columbia* mishap lessons learned.

NASA will review the lessons learned from the *Columbia* mishap and update the Program-level Contingency Action Plan to reflect those lessons. In addition, NASA will review and update the Headquarters Agency Contingency Action Plan for Space Flight Operations.

SSP-11 Remove and inspect Orbiter rudder speed brake (RSB) actuators for internal corrosion and recommend, if required, corrective actions.

NASA began an inspection program to determine the exact status of all Orbiter rudder speed brake actuators based on corrosion found in the OV-103 body flap actuators. After each actuator is inspected, they will either be refurbished or returned for installation.

SSP-12 NASA will review flight radar coverage capabilities and requirements for critical flight phases

In coordination with the Air Force Eastern Range, NASA is exploring improvements in radar assets used during Shuttle launches to identify and characterize potential debris liberated during ascent. Specific radar cross section signatures will be developed to facilitate identification of debris observed by radar.

SSP-13 NASA will verify that hardware processing and operations are within the hardware qualification and certification limits.

As a result of NASA's investigation into several Orbiter hardware failures that occurred before the Columbia accident, an action to all SSP projects and elements was issued in December 2002 to review their hardware qualification and verification requirements and verify that processing and operating conditions are consistent with the original hardware certification. This action was reissued by the PRCB as a return to flight action. Each project/element is to present completed plans and schedules for validating that hardware operating and processing conditions, along with environments or combined environments, are consistent with the original certification.

SSP-14 Determine critical orbiter impact locations and TPS damage size criteria that will require on-orbit inspection and repair. Determine minimum criteria for which repairs are necessary and maximum criteria for which repair is possible.

NASA has embarked on a substantial effort to determine the critical damage size criteria for on-orbit inspection and repair. NASA is developing models to accurately predict the damage resulting from a debris impact and to develop a comprehensive damage-tolerance testing plan. NASA is also developing more mature models to determine which damage is survivable and which damage must be repaired before safe entry.

SSP-15 NASA will identify and implement improvements in problem tracking, in-flight anomaly (IFA) disposition, and anomaly resolution process changes.

NASA has begun to identify and implement improvements to the problem tracking, in-flight anomaly disposition, and anomaly resolution processes. A team reviewed SSP and internal documentation and processes and audited performance for the past three Shuttle missions. They concluded that, while clarification of the requirements for the Problem Reporting and Corrective Action System is needed, the implementation of those requirements also needs improvement. Issues identified by the team include misinterpretations of definitions, resulting in misidentification of problems and noncompliance with tracking and reporting requirements.

CAIB Observations

The observations contained in Chapter 10 of the CAIB report expand upon the CAIB recommendations, touching on the critical areas of public safety, crew escape, Orbiter aging and maintenance, quality assurance, test equipment, and the need for a robust training program for NASA managers. NASA is committed to examining these observations and has already made significant progress in determining appropriate corrective measures. Future versions of the Implementation Plan will expand to include additional suggestions from various sources. This will ensure that beyond returning safely to flight, we are institutionalizing sustainable improvements to our culture and programs that will ensure we can meet the challenges of continuing to expand the bounds of human exploration.

Public Safety

O10.1-1 NASA should develop and implement a public risk acceptability policy for launch and re-entry of space vehicles and unmanned aircraft.

NASA is nearing completion of a draft document on public risk, including a risk acceptance policy. The NASA Safety and Mission Assurance Directors reviewed the final draft in October 2003 and their comments have been addressed. The document will enter NASA's formal approval process using the NASA Online Directives Information System by the end of January 2004.

O10.1-2 NASA should develop and implement a plan to mitigate the risk that Shuttle flights pose to the general public.

O10.1-3 NASA should study the debris recovered from *Columbia* to facilitate realistic estimates of the risk to the public during Orbiter re-entry.

Observations O10.1-1, O10.1-2 and O10.1-3 are addressed, in SSP Action 2; the SSP will evaluate relative risk to all persons and property underlying the entry flight path. This study will encompass all landing opportunities from each inclination to each of the three primary landing sites.

Crew Escape and Survival

O10.2-1 Future crewed-vehicle requirements should incorporate the knowledge gained from the *Challenger* and *Columbia* accidents in assessing the feasibility of vehicles that could ensure crew survival even if the vehicle is destroyed.

A multidisciplinary team at the NASA Johnson Space Center, called the Crew Survival Working Group (CSWG), is developing a report incorporating lessons learned from both the *Challenger* and the *Columbia* accidents. The CSWG has participation from the Flight Crew Operations, Engineering, and Space and Life Sciences Directorates. The CSWG report will provide recommendations for enhancing crew survivability for future crewed vehicles. NASA has also established a policy document that codifies human rating requirements for space flight vehicles.

Industrial Safety and Quality Assurance

O10.4-1 Perform an independently led, bottom-up review of the Kennedy Space Center Quality Planning Requirements Document to address the entire quality assurance program and its administration. This review should include development of a responsive system to add or delete government mandatory inspections.

Observation O10.4-1 is addressed in SSP Action 1; NASA chartered an Independent Assessment Team (IAT) to evaluate the effectiveness of the SSP's government mandatory inspection point verification process for the Shuttle Processing Directorate at Kennedy Space Center and the External Tank Project at the Michoud Assembly Facility. In January 2004, the IAT released a report with findings, recommendations, and observations related to GMIP policy, processes, and workforce. The IAT's preliminary findings, recommendations, and observations were briefed to Office of Space and Mission Assurance and Office of Space Flight, and the final IAT report has been provided to the Space Shuttle Program for implementation.

O10.4-2 Kennedy Space Center's quality assurance programs should be consolidated under one Mission Assurance office, which reports to the Center Director.

NASA will improve the observed deficiencies in basic quality assurance philosophy by developing a training program comparable to the Defense Contract Management Agency, using existing training programs where possible.

O10.4-3 Kennedy Space Center quality assurance management must work with NASA and perhaps the Department of Defense to develop training programs for its personnel.

NASA will improve the observed deficiencies in basic quality assurance philosophy by developing a training program comparable to the Defense Contract Management Agency, using existing training programs where possible.

O10.4-4 Kennedy Space Center should examine which areas of International Organization for Standardization 9000/9001 truly apply to a 20-year old research and development system like the Space Shuttle.

NASA, along with a team of industry experts, will evaluate the applicability of ISO 9000/9001 to United Space Alliance KSC operations. This evaluation will lead to a recommendation for future use of the standards or changes to surveillance or evaluations of the contractors.

Maintenance Documentation

O10.5-1 Quality and Engineering review of work documents for STS-114 should be accomplished using statistical sampling to ensure that a representative sample is evaluated and adequate feedback is communicated to resolve documentation problems.

NASA has performed a review and systemic analysis of STS-114 work documents for the time period of Orbiter Processing Facility roll-in through system integration test of the flight elements in the Vehicle Assembly Building. The STS-114 Systemic analysis led to six Corrective Action recommendations consistent with the technical observations noted in the STS-107/109 review. Teams were formed to determine the root cause and long-term corrective actions. These recommendations were assigned Corrective Action Requests that will be used to track the implementation and effectiveness of the corrective actions.

O10.5-2 NASA should implement United Space Alliance's suggestions for process improvement, which recommend including a statistical sampling of all

future paperwork to identify recurring problems and implement corrective actions.

Engineering and SMA organizations are evaluating and revising their surveillance plans. Required changes to the Ground Operations Operating Procedures are being identified, and the development of the QPRD change process for government inspection requirements and the supporting database is nearing completion. Additionally, NASA will improve communication between Engineering and SMA through the activation of a Web-based log and the use of the QPRD change process for government inspection requirements.

O10.5-3 NASA needs an oversight process to statistically sample the work performed and documented by United Space Alliance technicians to ensure process control, compliance, and consistency.

The CAIB observed the need for improvements in how NASA performs statistical sampling of documentation and of performed work. NASA formed a Processing Review Team to examine the processes addressed in the observations and expects to have recommendations by December.

Orbiter Maintenance Down Period/Orbiter Major Modification

O10.6-1 The Space Shuttle Program Office must make every effort to achieve greater stability, consistency, and predictability in Orbiter major modification planning, scheduling, and work standards (particularly in the number of modifications). Endless changes create unnecessary turmoil and can adversely impact quality and safety.

The practice of seeking approval for the implementation of all known modifications at the inception of the Orbiter Modification Down Period (OMDP) planning has been restored with the second OV-105 OMDP, currently approved to begin in December 2003. At the Modification Site Requirements Review in June 2003, the PRCB approved the inclusion of all modifications requested for implementation in this OMDP.

O10.6-2 NASA and United Space Alliance managers must understand workforce and infrastructure requirements, match them against capabilities, and take actions to avoid exceeding thresholds.

Additional personnel hiring, focusing on needed critical skill sets, is being coordinated with the NASA Shuttle Processing Directorate and the NASA Orbiter Project Office.

O10.6-3 NASA should continue to work with the U.S. Air Force, particularly in areas of program management that deal with aging systems, service life extension, planning and scheduling, workforce management, training, and quality assurance.

NASA has initiated a number of aging vehicle assessment activities as part of integrated Space Shuttle Service Life Extension activities. Each of the Space Shuttle element organizations is pursuing appropriate vehicle assessments to ensure that SSP operations remain safe and viable through 2020 and beyond. NASA is also continuing to solicit participation from government and industry aging system experts from across the aerospace and defense sectors. Specifically, NASA will continue to work with the U.S. Air Force in its development of aging vehicle assessment plans.

O10.6-4 The Space Shuttle Program Office must determine how it will effectively meet the challenges of inspecting and maintaining an aging Orbiter fleet before lengthening Orbiter major maintenance intervals.

NASA has initiated a number of assessments to ensure that Space Shuttle operations remain safe and viable throughout the Shuttle's service life. NASA has decided to keep the Orbiter Maintenance Requirements and Specifications Document intervals at 3 years or 8 flights to provide a higher level of confidence.

Orbiter Corrosion

O10.7-1 Additional and recurring evaluation of corrosion damage should include non-destructive analysis of the potential impacts on structural integrity.

O10.7-2 Long-term corrosion detection should be a funding priority.

O10.7-3 Develop non-destructive evaluation inspections to find hidden corrosion.

O10.7-4 Inspection requirements for corrosion due to environmental exposure should first establish corrosion rates for Orbiter-specific environments, materials, and structural configurations. Consider applying Air Force corrosion prevention programs to the Orbiter.

Orbiter Project Office has developed several recommendations to inspect and evaluate corrosion problems. In the next update to this Implementation Plan, we will provide

specific details on activities that have received SSP approval to proceed.

Brittle Fracture of A-286 Bolts

O10.8-1 Teflon (material) and Molybdenum Disulfide (lubricant) should not be used in the carrier panel bolt assembly.

O10.8-2 Galvanic coupling between aluminum and steel alloys must be mitigated.

O10.8-3 The use of Room Temperature Vulcanizing 560 and Koropon should be reviewed.

O10.8-4 Assuring the continued presence of compressive stresses in A-286 bolts should be part of their acceptance and qualification procedures.

The Orbiter Project Office has developed several recommendations to reassess the problems incurred with the components and materials addressed in O10.8-1 through O10.8-4. In the next update to this Implementation Plan, we will provide specific details on activities that have received SSP approval to proceed.

Hold-Down Post Cable Anomaly

O10.9-1 NASA should consider a redesign of the system, such as adding a cross-strapping cable, or conduct advanced testing for intermittent failure.

NASA evaluated five options for redesign of this system and has tentatively selected a configuration that will provide redundancy directly at the T-0 umbilical, which was determined to be the primary contributing cause of an anomaly in the Hold-Down Post Cable system on STS-112. Further assessment of this redesign option is ongoing. A cross-strapping cable was not recommended due to concerns that it would introduce a failure that could inhibit both hold-down post pyrotechnic systems. A NASA Headquarters sponsored Independent Assessment Team was formed to review the STS-112 anomaly and generically review the T-0 umbilical electrical/data interfaces.

Solid Rocket Booster External Tank Attachment Ring

O10.10-1 NASA should reinstate a safety factor of 1.4 for the Attachment Rings – which invalidates the use of ring serial numbers 16 and 15 in their present state – and replace all deficient material in the Attachment Rings.

The Solid Rocket Booster Project Office has completed a more accurate nonlinear analysis and inspection of the first flight set Attachment Rings and determined that all of the Attachment Rings meet NASA's factor of safety and safe-life requirements. Processing of the second flight set is under way. Testing, inspection, and, if necessary, replacement of all remaining flight hardware will ensure the remaining hardware inventory meets factor of safety requirements.

Test Equipment Upgrades

O10.11-1 Assess NASA and contractor equipment to determine if an upgrade will provide the reliability and accuracy needed to maintain the Shuttle through 2020. Plan an aggressive certification program for replaced items so that new equipment can be put into operation as soon as possible.

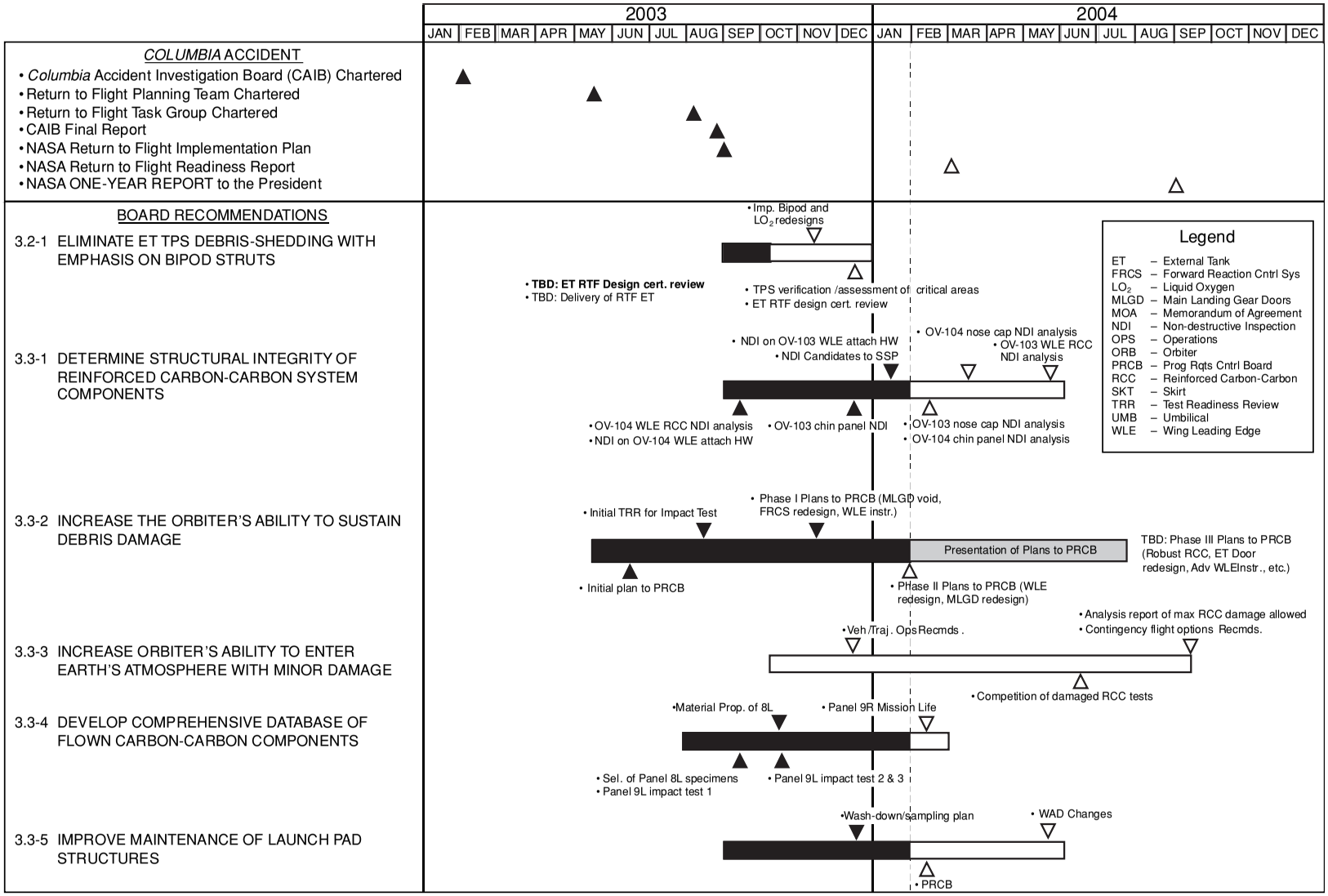
NASA has initiated an assessment of all critical Program equipment. NASA will continue to assess such equipment through the use of a health assessment process and annual supportability reviews; these assessments will be used to determine where upgrades are needed to support the upkeep and maintenance of the Shuttle fleet through 2020. Identified upgrades will be submitted through the Shuttle Service Life Extension process to ensure funding of specific projects.

Leadership/Managerial Training

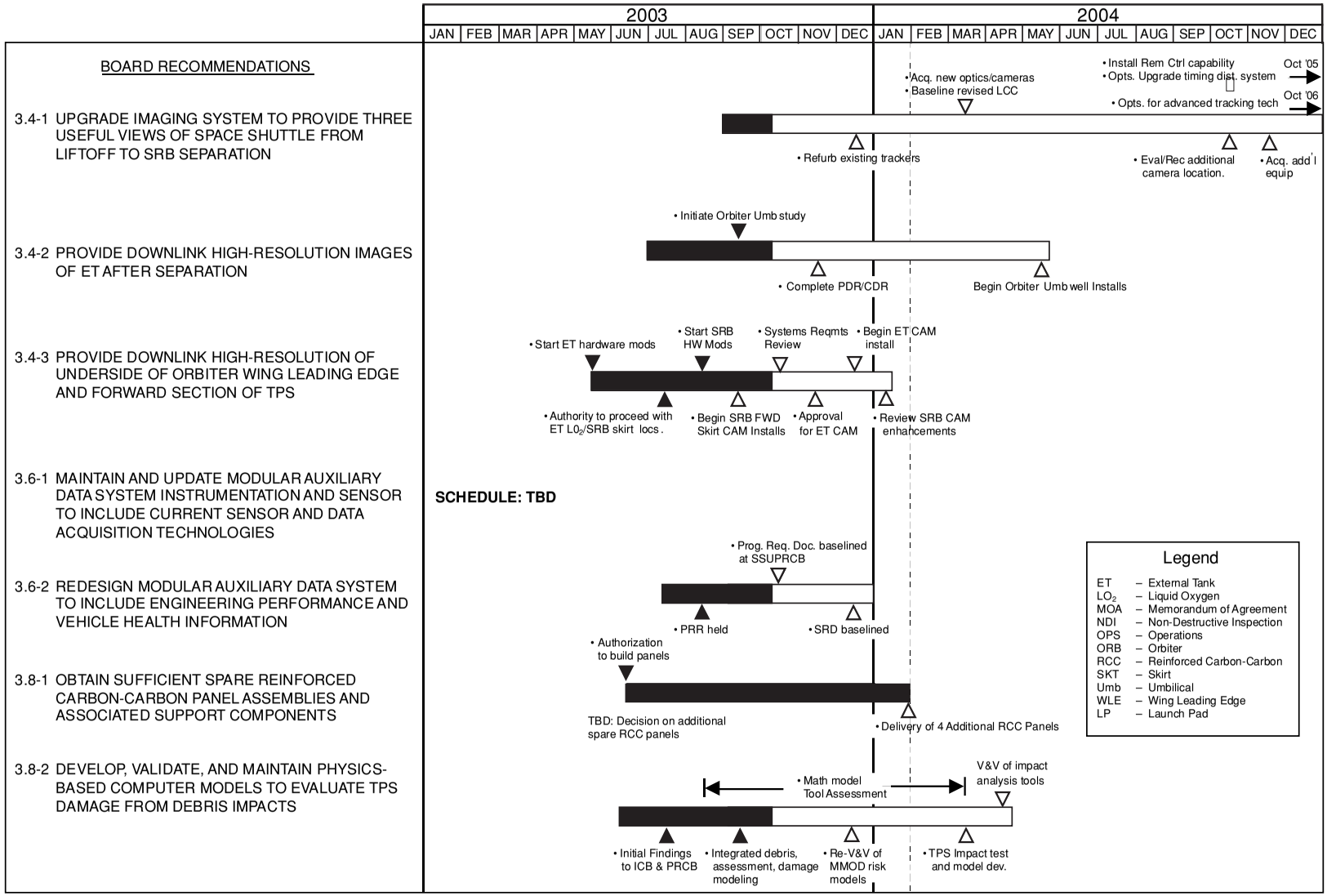
O10.12-1 NASA should implement an Agency-wide strategy for leadership and management training that provides a more consistent and integrated approach to career development. This strategy should identify the management and leadership skills, abilities, and experiences required for each level of advancement. NASA should continue to expand its leadership development partnerships with the Department of Defense and other external organizations.

The NASA Office Of Human Resources will establish an Agency team to address the development and implementation of an Agencywide strategy for leadership and management development training. The team will be composed of NASA leaders, Agency and center training and development staff, line managers, and a member from the academic community. NASA will benchmark the leadership and management development programs of other governmental agencies, major corporations, and universities. The Office will also conduct fact finding through such organizations as the American Society of Training and Development and the American Productivity and Quality Center.

CAIB Recommendations Implementation Schedule



CAIB Recommendations Implementation Schedule



CAIB Recommendations Implementation Schedule

BOARD RECOMMENDATIONS

4.2-1 TEST AND QUALIFY FLIGHT HARDWARE BOLT CATCHERS

4.2-2 DEVELOP STATE-OF-THE-ART MEANS TO INSPECT ORBITER WIRING AS PART OF SLEP

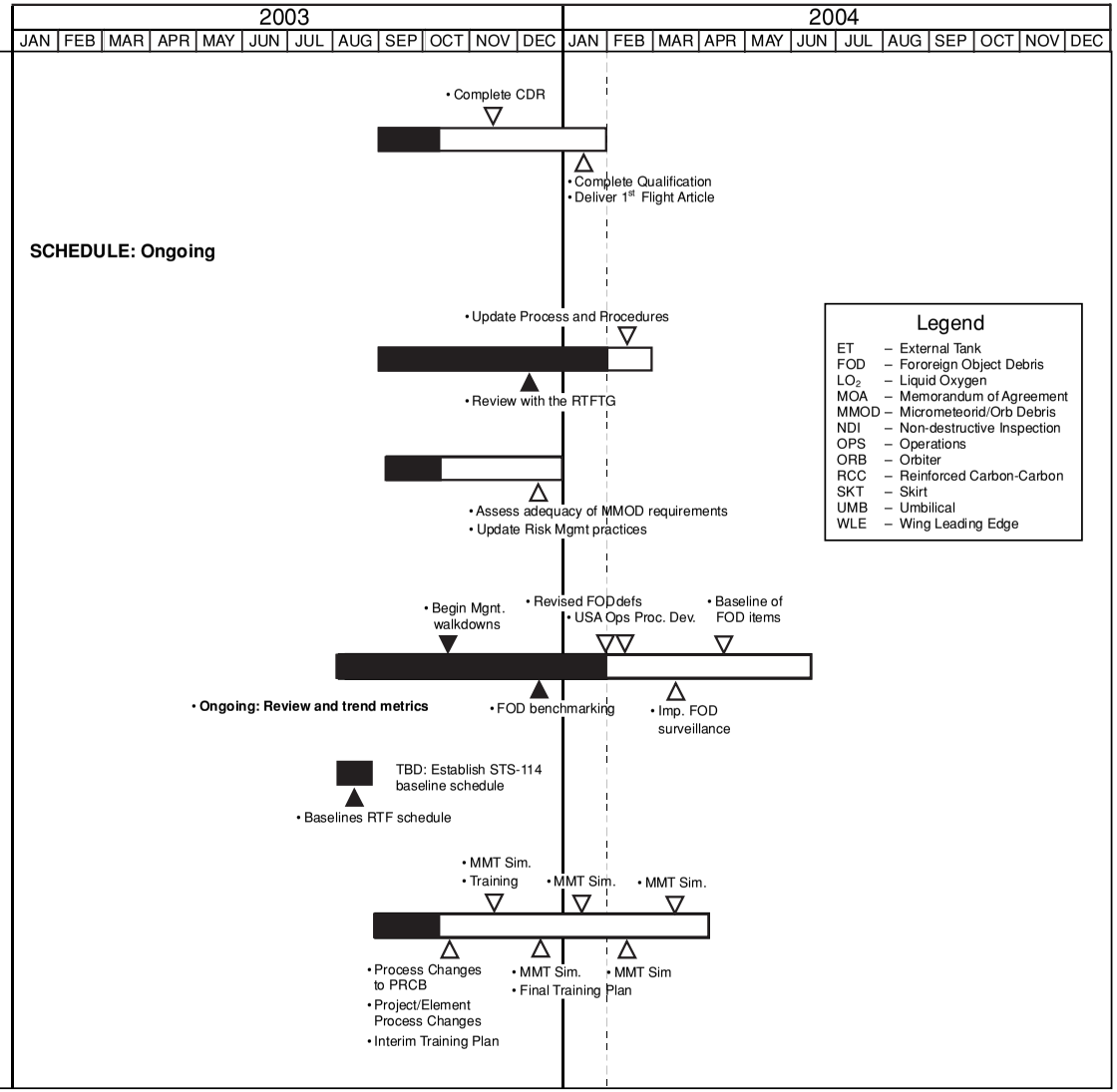
4.2-3 REQUIRE AT LEAST TWO EMPLOYEES ATTEND ALL FINAL CLOSEOUTS AND INTERTANK HAND SPRAYING PROCEDURES

4.2-4 REQUIRE SHUTTLE TO OPERATE WITH SAME DEGREE OF SAFETY FOR MICROMETEOROID AND ORBITAL DEBRIS AS ISS

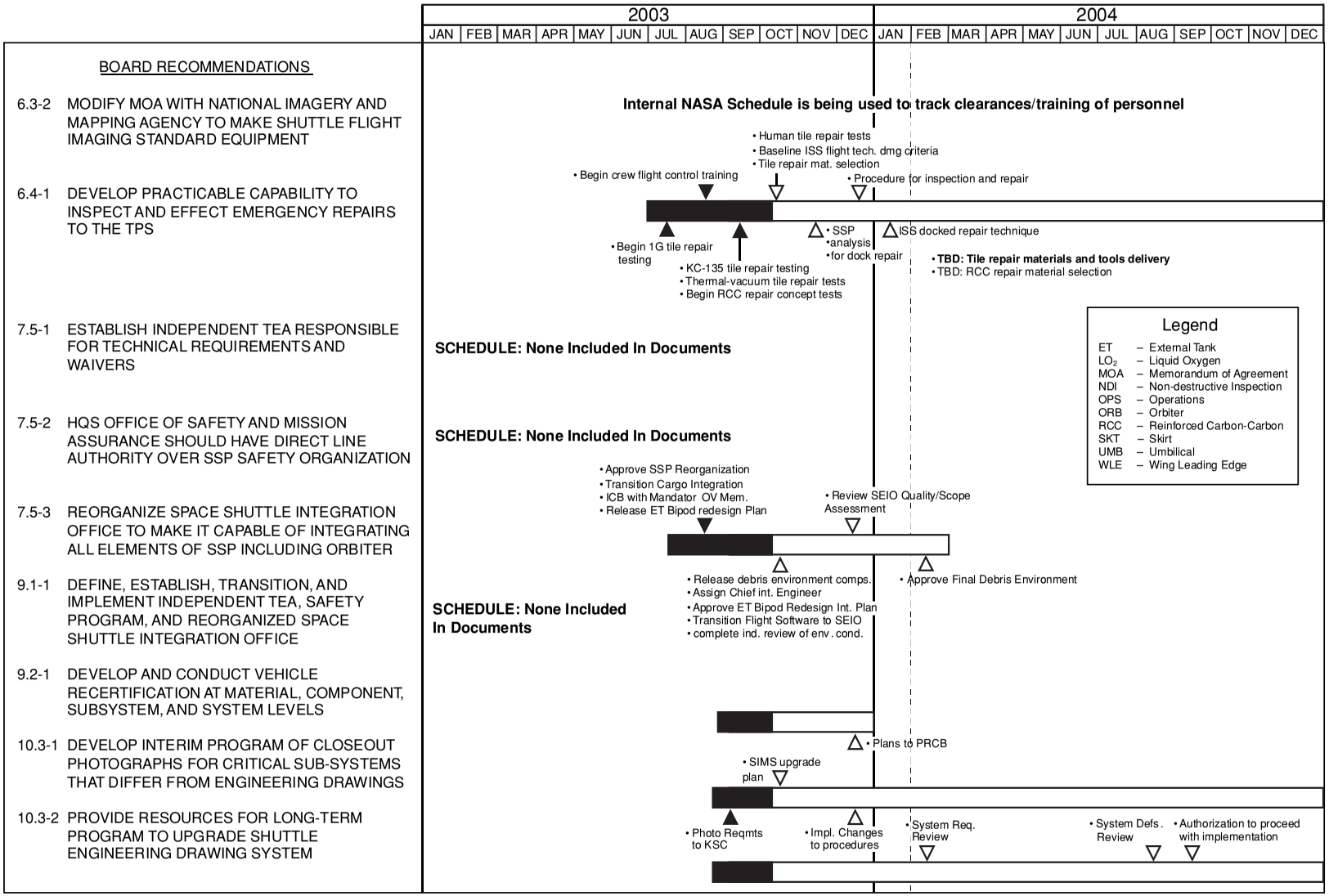
4.2-5 KSC QUALITY ASSURANCE AND USA MUST RETURN TO STRAIGHTFORWARD, INDUSTRY-STANDARD DEFINITION OF "FOREIGN OBJECT DEBRIS"

6.2-1 ADOPT AND MAINTAIN SHUTTLE FLIGHT SCHEDULE CONSISTENT WITH AVAILABLE RESOURCES

6.3-1 IMPLEMENT A TRAINING PROGRAM THAT THE MMT FACES POTENTIAL CREW AND VEHICLE SAFETY CONTINGENCIES



CAIB Recommendations Implementation Schedule



Return to Flight Cost Summary

NASA began to incur costs in FY 2003, originally estimated at approximately $40.5M, to initiate return to flight (RTF) actions based on preliminary CAIB recommendations and internal Shuttle Program actions. In November 2003, NASA identified a total of $60M of FY 2003 RTF activities that had sufficient maturity to allow reasonable cost estimates, and had been approved for funding by the Space Shuttle Program Requirements Control Board (PRCB) and verified by the RTF Planning Team (RTFPT). Since November, additional corrective actions have been initiated based on the final CAIB report recommendations and internal Shuttle Program actions. The total cost of FY 2003 RTF activities is now known to be $93.5M.

For FY 2004, $265M of potential RTF activities has been identified to date, of which $124M have been approved through the PRCB and verified by the RTF Planning Team. The remaining $141M of identified potential FY 2004 RTF activities is still under evaluation to confirm the estimated cost and associated out-year phasing. Cost estimates for RTF activities are dynamic. Additional funding may be required from other Agency sources. As soon as these additional RTF activities are definitized, they will be shared with Congress in the *NASA's Implementation Plan for Space Shuttle Return to Flight and Beyond.*

Not included in cost estimates provided are additional RTF elements being evaluated for a start in FY 2004 and other RTF funding requirements resulting from a complete evaluation of the CAIB report, such as replacement of hardware (e.g., cargo integration, Orbiter pressure tanks); other agencies' on-orbit assessment; and program reserves. Several solutions to improve NASA's culture and some of the Space Shuttle Program's (SSP) actions detailed in "Raising the Bar – Other Corrective Actions" (referred to as SSP corrective actions for the remainder of this summary) will be integrated into existing processes and may not always require additional funding.

The proposed SSP solutions for all RTF actions will be reviewed before receiving final NASA implementation approval and included in future updates. This process applies to solutions to the CAIB recommendations as well as to the SSP corrective actions.

The PRCB has responsibility to direct studies of identified problems, formulate alternative solutions, select the best solution, and develop overall cost estimates. The membership of the PRCB includes the SSP Manager, Deputy Manager, all Project and Element Managers, Safety and Mission Assurance personnel, and the Team Leader of the RTFPT.

PRCB deliberations are further evaluated by the RTFPT to ensure that comprehensive, integrated, and cohesive approaches are selected to address the recommendations and solutions as outlined in this plan. The membership of the RTFPT group includes approximately 30 experienced senior personnel from the Office of Space Flight and its field centers (at JSC, KSC, MSFC, and SSC).

In the process of down-selecting to two or three "best options," the projects and elements approve funding to conduct tests, perform analysis, develop prototype hardware and flight techniques, and/or obtain contractor technical expertise that is outside the scope of existing contracts.

The Space Flight Leadership Council (SFLC) is regularly briefed on the overall activities and progress associated with RTF and becomes directly involved when the SSP and RTFPT are ready to recommend a comprehensive solution to a CAIB recommendation or SSP corrective action. The SFLC receives a technical discussion of the solution as well as an assessment of cost and schedule. With the concurrence of the SFLC, the SSP then receives the authority to proceed. The membership of the SFLC includes the Associate Administrator for the Office of Space Flight, Associate Deputy Administrator for Technical Programs, Deputy Associate Administrator for ISS and SSP, Associate Administrator for Safety and Mission Assurance, RTFPT Team Lead, Space Shuttle Program Manager, and the Office of Space Flight Center Directors (at JSC, KSC, MSFC, and SSC).

All recommended solutions are further reviewed, for both technical merit and to determine if the solution responds to the action, by the Return to Flight Task Group (also known as the Stafford-Covey Task Group).

As decisions are made through the process described above, NASA will provide updated cost estimates in subsequent revisions of NASA's Implementation Plan for Space Shuttle Return to Flight and Beyond. Current estimates for NASA's initial RTF requirements are based on cost estimating relationships derived from previous cost history, and typically include costs such as studies, engineering, development, integration, certification, verification, implementation, and retrofit, if appropriate.

Return to Flight Budget Estimates/Implementation Plan Map for New Estimates Including Threats As of 1/29/04

	($ Millions)		Recommendation Numbers Map to Implementation Plan														
	FY 03	FY 04	CAIB #3.2-1	CAIB #3.3-1	CAIB #3.3-2	CAIB #3.3-3	CAIB #3.3-4	CAIB #3.4-1	CAIB #3.4-2	CAIB #3.4-3	CAIB #4.2-1	CAIB #4.2-3	CAIB #6.4-1	CAIB #7.5-1	CAIB #7.5-2	CAIB #9.1-1	SSP Recommendation
Initiated RTF Activities	**92**	**264**															
Orbiter RCC Inspections	4	21		X									X				
On-orbit TPS Inspection & EVA Tile Repair	46	53											X				
Orbiter TPS Hardening	4	17			X												
Orbiter Certification / Verification	2	3		X		X	X										
External Tank Items (Camera, Bipod Ramp, etc.)	26	60	X					X	X	X		X					
SRB Items (Bolt Catcher, ETA Ring Invest., Camera)	0	14							X	X	X						
Ground Camera Ascent Imagery Upgrade	8	36						X	X	X							
Other (System Intgr. JBOSC Sys, SSME Tech Assess)	2	60		X		X	X										
Stafford - Covey Team	**2**	**1**															X
Total SSP RTF Related	**94**	**265**															
Other RTF Related																	
NASA Engineering and Safety Center (NESC)		**45**												X	X	X	

Columbia Accident Investigation Board

Recommendation 3.3-2

Initiate a program designed to increase the Orbiter's ability to sustain minor debris damage by measures such as improved impact-resistant Reinforced Carbon-Carbon and acreage tiles. This program should determine the actual impact resistance of current materials and the effect of likely debris strikes. [RTF]

BACKGROUND

The STS-107 accident demonstrated that the Space Shuttle Thermal Protection System (TPS) design is vulnerable to impact damage for conditions outside the current design criteria. Identification of all sources of debris and potential modifications to the design of the TPS, referred to as Orbiter hardening, are expected to make the Orbiter less vulnerable to this risk.

NASA IMPLEMENTATION

A Program Requirements Control Board (PRCB) action authorizes assessment of potential TPS modifications for Orbiter hardening. As part of this action, NASA is defining candidate redesigns that will reduce impact damage risk to vulnerable TPS areas and is also developing an assessment plan for other steps to improve Orbiter hardening.

In March 2003, a planning team integrated concepts for Orbiter hardening into the following seven candidate TPS design families: landing gear and External Tank (ET) door TPS and structure; wing leading edge (WLE) subsystem; vehicle carrier panels and attachments; critical area lower surface tile; elevon gap and cove TPS and seals; critical Orbiter maneuvering system pod and vertical tail areas; and nose cap and chin panel subsystem.

Within these seven design families (figure 3.3-2-1), 17 conceptual design candidates were developed in April 2003. These candidates ranged from near-term (one year or less implementation time) with low technical risk to very long-term (greater than three-year implementation time) with high technical risk. NASA directed the planning team to continue working with problem-resolution teams to define study and implementation priorities, with focus on near-term options.

In May 2003, a TPS enhancement Orbiter hardening technical interchange meeting addressed all 17 conceptual design candidates. The results of this meeting were presented to the PRCB in June 2003, including forward action plan recommendations for the following TPS/WLE enhancement redesign options (listed in order of priority):

- WLE Redesign—Options include WLE carrier panel and fastener redesign, spar insulation, and new WLE surface coating materials to provide additional protection against impact and plasma flow vulnerability.
- Durable Tile—Complete development of tougher lower surface landing gear door and ET door periphery tiles, elevon leading edge and wing trailing edge carrier panel tiles and window frames, and acreage tile. Also, complete development of ballistic strain isolation pad material.
- Landing Gear Door and ET Door Redesign—Options include upgrade of thermal barrier materials to provide better protection against high temperatures, and multiple thermal barrier backup capability to main landing gear doors (MLGDs).
- Carrier Panel Upgrades to Eliminate Bonded Studs and Elevon Leading Edge Carrier Panel Installation Redesign—Redesign of carrier panel attachments to eliminate failure mode of structural bonds to ensure positive margins. Redesign access panels to improve protection against impacts and provide additional protection from plasma flow due to impact damage.
- TPS Instrumentation—Define additional instrumentation needs, sensor types, and avionics modifications; determine requirements for data trending. Installation of an impact penetration instrumentation system to provide monitoring capability for potential ascent/micrometeoroid and orbital debris impacts.
- White Toughened Unipiece Fibrous Insulation (TUFI) Tiles—Lessen impact damage susceptibility of certain upper surface tiles by replacing existing tile with white TUFI tile.
- Vertical Tail Advanced Flexible Reusable Surface Insulation (AFRSI) High-Emittance Coating—Add high-emittance coating to existing AFRSI blankets to expand contingency low-alpha reentry trajectory limits.

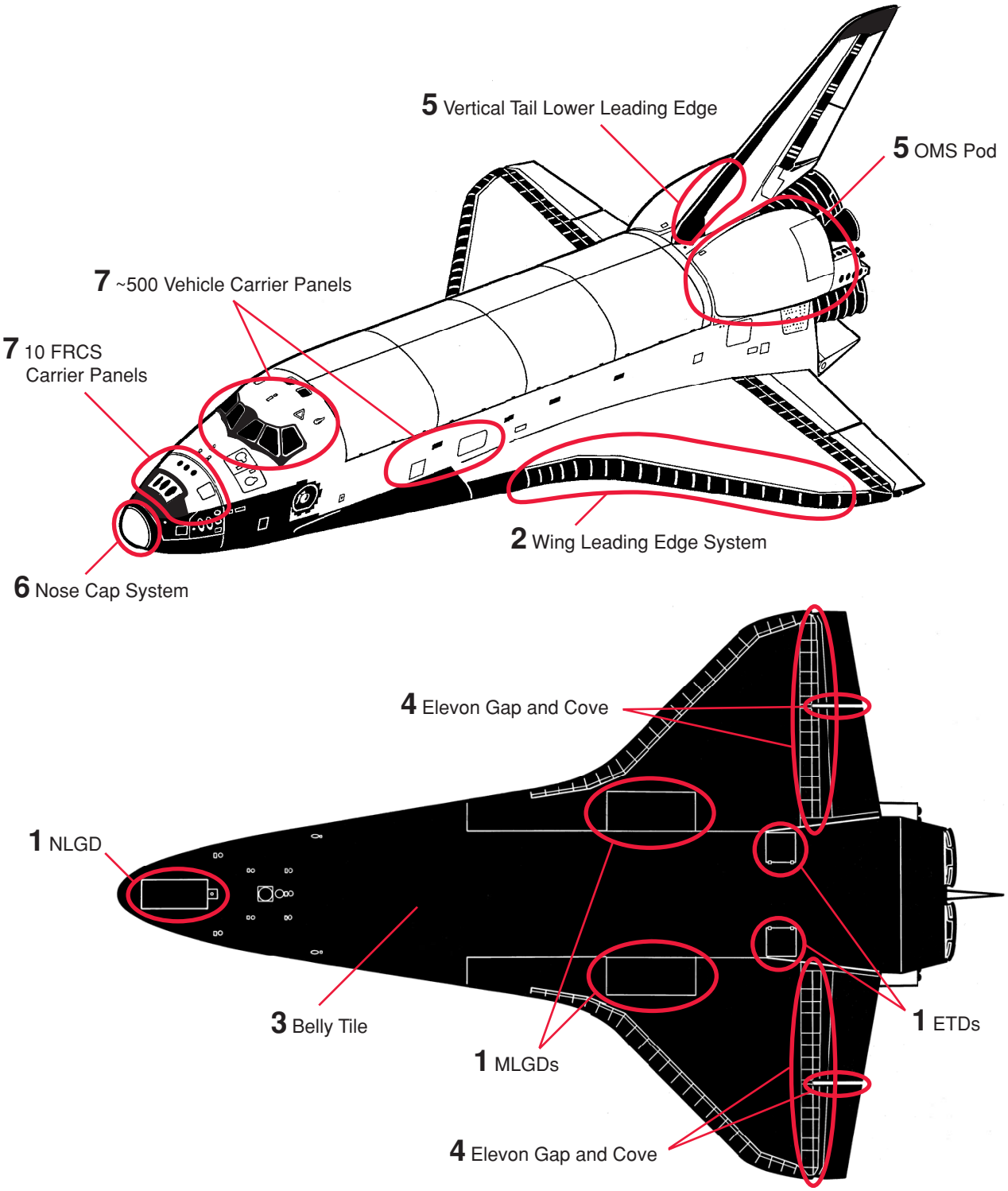


Figure 3.3-2-1. Seven critical TPS families targeted for enhancement.

- Robust Reinforced Carbon-Carbon (RCC) Replacement Study—Apply new technologies to develop a more debris-tolerant material for the nose cap, chin panel, and WLE panels.

The Space Shuttle Program (SSP) has established a plan to determine the impact resistance of both RCC and tiles in their current configurations. The SSP is also working to identify all debris sources from all Space Shuttle elements including the ET, the Solid Rocket Boosters, and the Orbiter. The SSP Systems Engineering and Integration Office is providing transport analyses to identify potential velocity, impact location, and impact angle for the debris sources. In parallel, an impact test program is being conducted to determine the impact resistance of RCC and tile using various debris sources under conditions that encompass the full range of parameters provided by the transport analysis. The data generated from this testing will be used to correlate an accurate set of analytical models to further understand the damage threat. Further testing will be conducted on specific Orbiter insulation configurations that were identified during the investigation, including the leading edge structural subsystem access panels (located directly behind the RCC) and the edge tile configuration of the MLGD.

STATUS

For each of the eight redesign options listed above, NASA is developing detailed feasibility assessments that will include cost and schedule for either full implementation or for the next proposed phase of the project. The Orbiter hardening options have been grouped into three categories based on the implementation phasing. Phase I options will be implemented before return to flight. Phase II includes potential constraints to flight; additional tests and analyses may require some of these options to be moved to Phase I. Phase III consists of the long-term options that will increase the Orbiter's impact resistance capability. The qualification and certification of one Phase III option, tougher lower and upper surface tiles, has been approved by the SSP. This and the other modifications wll be implemented as material development is completed and opportunities become available.

Debris sources are being identified, and test plans are being generated for the TPS impact tests. Three full-scale impact tests of RCC were conducted at Southwest Research Institute. The first test used a foam projectile of 0.1 lb. mass at 700 ft/sec (fps), and the second test doubled the kinetic energy of the initial test by using a 0.2 lb. projectile at 700 fps. Neither test resulted in damage to the RCC panel. The third test again doubled the kinetic energy by using a 0.16 lb. projectile at 1167 fps. This test resulted in multiple through cracks and permanent deflections in the RCC panel.

FORWARD WORK

We will continue to implement the plan according to the schedule below. Decision packages for each redesign option will be brought to the PRCB for disposition.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Jun 03 (Complete)	Initial plan reported to PRCB
SSP	Aug 03 (Complete)	Initial Test Readiness Review held for Impact Tests
SSP	Nov 03 (Complete)	Phase I Implementation Plans to PRCB (MLGD corner void, Forward Reaction Control System (FRCS) carrier panel redesign—bonded stud elimination, and WLE impact detection instrumentation)
SSP	Jan 04	Phase II Implementation Plans to PRCB (WLE front spar protection and horse collar redesign, MLGD redundant thermal barrier redesign)
SSP	TBD	Phase III Implementation Plans to PRCB (included robust RCC, ET door thermal barrier redesign, advanced WLE instrumentation, elevon cove leading edge carrier panel redesign, etc.)

Columbia Accident Investigation Board

Recommendation 3.3-1

Develop and implement a comprehensive inspection plan to determine the structural integrity of all Reinforced Carbon-Carbon system components. This inspection plan should take advantage of advanced non-destructive inspection technology. [RTF]

BACKGROUND

Current on-vehicle inspection techniques are determined to be inadequate to assess the structural integrity of Reinforced Carbon-Carbon (RCC) components and attachment hardware. There are two aspects to the problem: (1) how we assess the structural integrity of RCC components and attach hardware throughout their service life, and (2) how we verify that the flight-to-flight RCC mass loss caused by aging does not exceed established criteria. At present, structural integrity is assured by wide design margins; comprehensive nondestructive inspection (NDI) is conducted only at the time of component manufacture. Mass loss is also monitored through a destructive test program that periodically sacrifices flown RCC panels to verify by test that the actual material proprties of the panels are within the predictions of the mission life model.

The RCC NDI techniques currently certified include X-ray, ultrasound (wet and dry), eddy current, and computer-aided tomography (CAT) scan. Of these, only eddy current can be done without removing components from the vehicle. While eddy current testing is useful for assessing the health of the RCC outer coating and detecting possible localized subsurface oxidation and mass loss, it reveals little about a component's internal structure. Since the other certified NDI techniques require hardware removal, each presents its own risk of unintended damage. Only the vendor is fully equipped and certified to perform RCC X-ray and ultrasound, even with hardware removed from the Orbiter.

Shuttle Orbiter RCC components are pictured in figure 3.3-1-1.

NASA IMPLEMENTATION

The Space Shuttle Program (SSP) is pursuing inspection capability improvements using newer technologies to allow comprehensive NDI of the RCC without removing it from the vehicle. A technical interchange meeting held in May 2003 included NDI experts from across the country. This meeting highlighted five techniques with potential for near-term operational deployment: flash thermography, ultrasound (wet and dry), advanced eddy current, shearography, and radiography. The SSP must still assess the suitability of commercially available equipment and standards for flight hardware. Once an appropriate in-place inspection method is fielded, the Program will be able to positively verify the structural integrity of RCC hardware without risking damage by removing the hardware from the vehicle.

NASA is committed to clearing the RCC by certified inspection techniques before return to flight (RTF). The near-term plan calls for removing all RCC components and returning them to the vendor for comprehensive NDI. For the long term, a Shuttle Program Requirements Control Board (PRCB) action was assigned to review inspection criteria and NDI techniques for all Orbiter RCC nose cap, chin panel, and wing leading edge (WLE) system components. Viable NDI candidates were reported to the PRCB in January 2004 and specific options were chosen.

RCC structural integrity and mass loss estimates will be validated by off-vehicle NDI of RCC components. All WLE panels, seals, nose caps, and chin panels will be removed from Orbiter Vehicles (OV)-103, OV-104, and OV-105 and returned to the vendor's Dallas, Texas, facility for comprehensive NDI. Inspections will include a mix of ultrasonic, X-ray, and CAT scan techniques. In addition, NASA has introduced off-vehicle flash thermography for all WLE panels and accessible nose cap and chin panel surfaces; any questionable components will be subjected to CAT scan for further evaluation. Data collected will be used to support development of future in-place NDI techniques.

The health of RCC attach hardware will be assessed using visual inspections and NDI techniques appropriate to the critical flaw sizes inherent in these metallic components. This NDI will be performed on select components from OV-103 and OV-104 with priority given to OV-104. Destructive evaluation of select attach hardware from both vehicles will also be undertaken. Additional requirements

will be established, if necessary, upon completion of initial inspections.

STATUS

Advanced On-Vehicle NDI: Near-term advanced NDI technologies were presented to the PRCB in January 2004. Thermography, contact ultrasonics, eddy current, and radiography were selected as the most promising techniques to be used for on vehicle inspection that could be developed in less than 12 months. The PRCB approved the development of these techniques.

OV-104: The nose cap, chin panel, and all WLE RCC panel assemblies have been removed from the vehicle and shipped to the vendor for complete NDI. Completion of the data analysis from this suite of inspections is planned in March 2004. Inspection of all WLE panels is complete, and completion of the analysis of the final panel is expected in February 2004. Eddy current inspections of the nose cap and chin panel were completed before these components were removed; and the results compare favorably to data collected when the components were manufactured, indicating mass loss and coating degradation are within acceptable limits. Off-vehicle vendor inspection is expected to confirm this assessment.

OV-103: As part of the OV-103 Orbiter maintenance down period (OMDP), WLE panels were removed from the vehicle, inspected by visual and tactile means, and then shipped to the vendor for NDI. The analysis of the inspection results will be completed in May 2004. X-ray inspection of the RCC nose cap, which was already at the vendor for OMM coating refurbishment, revealed a previously undocumented 0.025 in. × 6 in. tubular void in the upper LH expansion seal area. While this discrepancy does not meet manufacturing criteria, it is located in an area of the panel with substantial design margin (900% at end of panel life) and is acceptable for flight. The suite of inspections performed on the OV-103 nose cap has confirmed the Orbiter's flight worthiness and, to date, revealed nothing that might call into question the structural integrity of any other RCC component.

OV-105: All OV-105 RCC components (WLE, nose cap, and chin panel) will be removed and inspected during its OMDP, which began in July 2003.

RCC Attach Hardware: The RCC Problem Resolution Team was given approval for a plan for attach hardware NDI and destructive evaluation.

FORWARD WORK

OV-104 RCC system readiness for flight will be based on results of ongoing WLE, nose cap, and chin panel inspections, and NDI.

The near-term advanced on-vehicle NDI techniques are in development, as well as the process and standards for their use. Decisions on long-term NDI techniques (those requiring more than 12 months to develop) will be made after inspection criteria are better established.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Sep 03 (43 of 44 panels complete, last panel complete in Feb 04)	OV-104 WLE RCC NDI analysis complete
SSP	Oct 03 (Complete)	Completion of NDI on OV-104 WLE attach hardware
SSP	Dec 03 (Complete)	OV-103 chin panel NDI
SSP	Jan 04 (Complete)	Report viable on-vehicle NDI candidates to the SSP
SSP	Jan 04 (Complete)	Completion of NDI on OV-103 WLE attach hardware
SSP	Feb 04	OV-103 nose cap NDI analysis complete
SSP	Feb 04	OV-104 chin panel NDI analysis complete
SSP	Mar 04	OV-104 nose cap NDI analysis complete
SSP	May 04	OV-103 WLE RCC NDI analysis complete

Columbia Accident Investigation Board

Recommendation 3.3-4

In order to understand the true material characteristics of Reinforced Carbon-Carbon components, develop a comprehensive database of flown Reinforced Carbon-Carbon material characteristics by destructive testing and evaluation.

BACKGROUND

The only material properties data for flown Reinforced Carbon-Carbon (RCC) components is from two panels, both of which were destructively tested by the Space Shuttle Program (SSP). Both panels were removed from Orbiter Vehicle (OV)-102. One panel, 10 left (10L), was tested after 19 flights and the other panel, 12 right (12R), was tested after 15 flights. The results from these tests were compared to the analytical model and indicated that the model was conservative.

NASA IMPLEMENTATION

An RCC material characterization program is under way using existing flight assets to obtain data on strength, stiffness, stress-strain curves, and fracture properties of RCC for comparison to earlier testing data. The SSP has established a plan to determine the impact resistance of RCC in its current configuration using previously flown panels, those with 26-30 flights. In addition, tension, compression, in-plane shear, interlaminar shear, and high strain rate properties will be developed. Data on the attachment lug mechanical properties, corner mechanical properties, and coating adherence will also be obtained. NASA will maintain a comprehensive database developed with the information from these evaluations and characterization programs.

STATUS

Panel 8L (OV-104 with 26 flights) is being dissected now to provide test articles to several teams performing the analysis of material properties. Panel 6L (OV-103 with 30 flights) will be used to perform thermal and mechanical testing for material susceptibility to crack propagation during the flight envelope. Panels 9L (OV-103 with 27 flights) and 10L (OV-103 with 30 flights) will be used to determine the impact capability of the RCC. Panel 9R (with 30 flights) from OV-103 will be destructively tested, using methods similar to those used on Panels 10L and 12R, to compare its material properties to the analytical model and to add to the database.

FORWARD WORK

The study of materials and processes will be central to understanding and cataloging the material properties and their relation to the overall health of the subsystem. Materialography and material characteristics (porosity, coating/substrate composition, etc.) for RCC panels are being evaluated with the objective of correlating mechanical property degradation to microstructural/chemical changes and nondestructive inspection results. Once developed, the database will be used to direct design upgrades, mission/life adjustments, and other critical concerns as long as the leading edge structural subsystem continues to be used. The long-term plan will include additional RCC assets as required to ensure that the database is fully populated (reference R3.8-1).

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Sep 03 (Complete)	Section of Panel 8L test specimens for material property testing
SSP	Sep 03 (Complete)	Panel 9L impact test number 1
SSP	Sep/Oct 03 (Complete)	Material property testing of Panel 8L specimens
SSP	Oct 03 (Complete)	Panel 9L impact test number 2 and 3
SSP	June 04	Panel 9R mission life material properties testing for comparison to the analytical model

Columbia Accident Investigation Board

Recommendation 3.3-5

Improve the maintenance of launch pad structures to minimize the leaching of zinc primer onto Reinforced Carbon-Carbon components.

BACKGROUND

Zinc coating is used on launch pad structures to protect against environmental corrosion. "Craze cracks" in the Reinforced Carbon-Carbon (RCC) panels allow rain water and leached zinc to penetrate the panels and cause pinholes.

NASA IMPLEMENTATION

Before return to flight (RTF), Kennedy Space Center (KSC) will enhance the launch pad structural maintenance program to reduce RCC zinc oxide exposure to prevent zinc-induced pinhole formation in the RCC (figure 3.3-5-1). The enhanced program has four key elements. KSC will

1. Enhance the postlaunch inspection and maintenance of the structural coating system, particularly on the rotating service structure. Exposed zinc primer will be recoated to prevent liberation and rainwater transport of zinc-rich compounds.
2. Assess postlaunch pad structural wash-downs to determine if they can be enhanced to minimize the corrosive effects of acidic residue on the pad structure. This will help prevent corrosion-induced damage to the topcoat and prevent exposure of the zinc primer.
3. Investigate options to improve the physical protection of Orbiter RCC hardware.
4. Implement a sampling program to monitor the effectiveness of efforts to inhibit zinc oxide migration on all areas of the pad structure.

STATUS

NASA is pursuing enhanced inspection, structural maintenance, wash-down, and sampling options to reduce zinc leaching. Changes to applicable work authorization documents are being formulated and will be incorporated before RTF.

NASA is developing options for enhanced physical protection. The options developed will be presented to the Program Requirements Control Board (PRCB) when available.

FORWARD WORK

The RCC Problem Resolution Team will continue to identify and assess potential mechanisms for RCC pinhole formation. Options for enhanced physical protection of RCC will be implemented as soon as they are approved and design is complete.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Space Shuttle Program (SSP)	Dec 03 (Complete)	Complete enhanced inspection, maintenance, wash-down, and sampling plan
SSP	Feb 04	Present to the PRCB options for enhanced physical protection of RCC hardware at the launch pads
SSP	May 04	Incorporate required Work Authorization Document changes

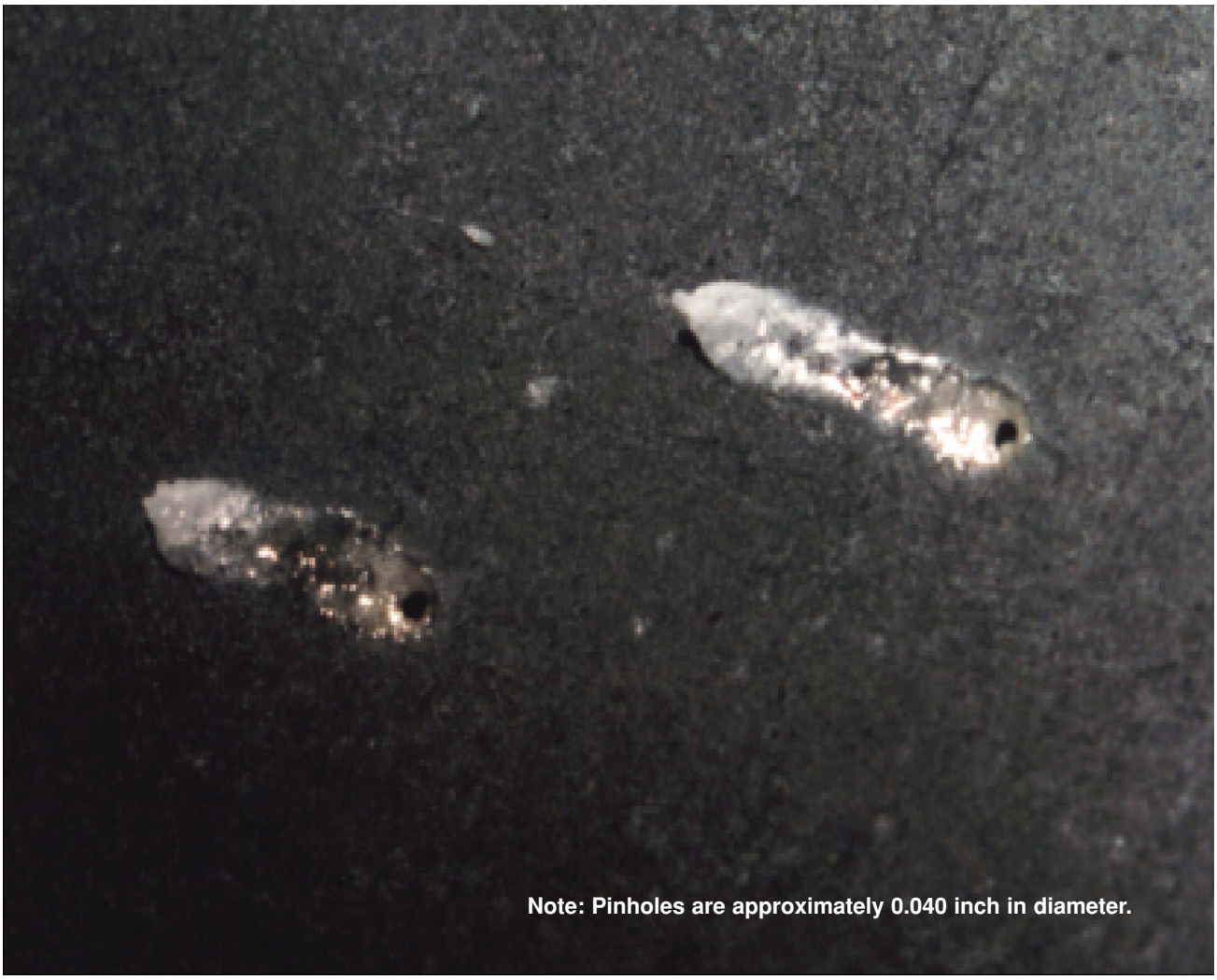


Figure 3.3-5-1. RCC pinholes.

Columbia Accident Investigation Board

Recommendation 3.8-1

Obtain sufficient spare Reinforced Carbon-Carbon panel assemblies and associated support components to ensure that decisions related to Reinforced Carbon-Carbon maintenance are made on the basis of component specifications, free of external pressures relating to schedules, costs, or other considerations.

BACKGROUND

There are 44 wing leading edge (WLE) panels installed on an Orbiter. All of these components are made of Reinforced Carbon-Carbon (RCC). The panels in the hotter areas, panels 6 through 17, have a useful mission life of 50 flights or more. The panels in the cooler areas, panels 1 through 5 and 18 through 22, have longer lives extending as high as 100 flights depending on the specific location. The "hot" panels (6–17) are removed from the vehicle every other Orbiter maintenance down period and are shipped to the original equipment manufacturer, Lockheed Martin, for refurbishment. Because these panels have a long life span, we have determined that a minimum of one spare ship-set is sufficient for flight requirements.

Since few panels have required replacement, few new panels have been produced since the delivery of Orbiter Vehicle (OV)-105. Currently, Lockheed Martin is the only manufacturer of these panels.

NASA IMPLEMENTATION

NASA's goal is to maintain a minimum of one spare ship-set of RCC WLE panel assemblies. To achieve this goal, four additional panel assemblies are required to have a complete spare ship-set.

The last of these panels will be available no later than January 2005.

STATUS

The buildup of RCC panels requires the use of carbonized rayon fabric, silicon carbide, tabular alumina, silicon metal, tetraethylorthosilicate [TEOS], Prepreg, and Sermabond 487. In addition to the four panels needed to complete one entire ship-set, there are enough raw materials currently available to build up to four additional ship-sets of RCC panels.

FORWARD WORK

The Space Shuttle Program (SSP) is developing a prioritized list of additional spare panels that will be ordered through United Space Alliance after the initial four panels are delivered.

Research is ongoing to determine if there are options for increasing the robustness of the RCC panels. The decision to build RCC panels in addition to those needed to complete the minimum of one ship-set will be delayed until this research is complete.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Jun 03 (Complete)	Authorization to build four panels to complete ship-set
SSP	Jan 05	Delivery of four additional panels
SSP	TBD	Decision on additional space RCC panels (pending SSP decision on RCC enhancements)

Columbia Accident Investigation Board

Recommendation 4.2-3

Require that at least two employees attend all final closeouts and intertank area hand-spraying procedures. [RTF]

BACKGROUND

External Tank (ET) final closeouts and intertank area hand-spraying processes typically require more than one person in attendance to execute procedures. Those close-out processes that can currently be performed by a single person did not necessarily specify an independent witness or verification.

NASA IMPLEMENTATION

NASA has established a Thermal Protection System (TPS) verification team to verify, validate, and certify all future foam processes. The verification team will assess and improve the TPS applications and manual spray processes. Included with this assessment is a review and an update of the process controls applied to foam applications, especially the manual spray applications. Spray schedules, acceptance criteria, quality, and data requirements will be established for all processes during verification using a Material Processing Plan (MPP). The plan will define how each specific part closeout is to be processed. Numerous TPS processing parameters and requirements will be enhanced, including additional requirements for observation and documentation of processes. In addition, a review is being conducted to ensure the appropriate quality coverage based on process enhancements and critical application characteristics.

The MPPs will be revised to require, at a minimum, that all ET critical hardware processes, including all final closeouts and intertank area hand-spray procedures, be performed in the presence of two certified Production Operations employees. The MPPs will also include a step to require technicians stamp the build paper to verify their presence and validate the work was performed according to plan. Additionally, quality control personnel will witness and accept each manual spray TPS application. Government oversight of TPS applications will be determined upon completion of the revised designs and the identification of critical process parameters.

STATUS

The Space Shuttle Program (SSP) has approved the revised approach for ET TPS certification and the Space Flight Leadership Council approved it for Return to Flight Task Group (RTFTG) review. TPS verification activities are under way and specific applicable ET processing procedures are under review.

FORWARD WORK

Complete the TPS verification activities and implement the modifications, including modifying the MPPs to reflect the requirement that a minimum of two certified Production Operations employees be present for critical hardware processes.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Dec 03 (Complete)	Review revised processes with the RTFTG
SSP	Feb 04	Update TPS processes and procedures to incorporate recommendations

Columbia Accident Investigation Board

Recommendation 4.2-5

Kennedy Space Center Quality Assurance and United Space Alliance must return to the straightforward, industry standard definition of "Foreign Object Debris", and eliminate any alternate or statistically deceptive definitions like "processing debris". [RTF]

BACKGROUND

Beginning in 2001, foreign object debris (FOD) work at Kennedy Space Center was divided into two categories, "processing debris" and "FOD." FOD was defined as debris found during the final or flight-closeout inspection process. All other debris was labeled processing debris. The categorization and subsequent use of two different definitions of debris led to the perception that processing debris was not a concern.

NASA IMPLEMENTATION

NASA will stop using the term "processing debris." A team of NASA and United Space Alliance (USA) employees will benchmark similar industry and Department of Defense (DoD) processing facilities. Aferwards, a consistent definition of FOD will be developed and implemented across all processing activities. NASA and USA Shuttle processing operating procedures will be updated and metrics will be developed to reflect the definition change.

Approximately two months after the development of the improved FOD control program, NASA will perform a baseline audit. In addition, NASA will include FOD as an element of surveillance activities (e.g., hardware surveillance, process surveillance, and process sampling activities). NASA management will also participate in periodic walkdowns of processing areas for all three shifts.

The new FOD control program will be rolled out to all employees. And the FOD training and the FOD Web site will be updated and improved.

STATUS

The team completed both benchmarking trips, visiting four installations, and is documenting the results and comparing them with the KSC FOD Program. A preliminary definition has been developed, but will not be finalized until late January. In addition, the contractor and NASA managers are conducting inspection walkdowns.

FORWARD WORK

Remaining work includes documenting the FOD Program as an operating procedure, implementing increased NASA surveillance, and performing a baseline audit of the improved FOD Program.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Space Shuttle Program (SSP)	Ongoing	Review and trend metrics
SSP	Oct 03 (Complete)	Initiate NASA Management Walkdowns
SSP	Dec 03 (Complete)	FOD Control Program benchmarking
SSP	Jan 04	Revised FOD definition
SSP	Feb 04	USA Operating Procedure developed
SSP	Mar 04	Implement FOD surveillance
SSP	Apr 04	Baseline audit of Implementation of FOD definition, training, and surveillance

Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 1

NASA will commission an assessment, independent of the Space Shuttle Program (SSP), of the Quality Planning and Requirements Document (QPRD) to determine the effectiveness of government mandatory inspection point (GMIP) criteria in assuring verification of critical functions before each Shuttle mission. The assessment will determine the adequacy of existing GMIPs to meet the QPRD criteria. Over the long term, NASA will periodically review the effectiveness of the QPRD inspection criteria against ground processing and flight experience to verify that GMIPs are effectively assuring safe flight operations.

BACKGROUND

The *Columbia* Accident Investigation Board report highlighted the Kennedy Space Center (KSC) and Michoud Assembly Facility (MAF) government mandatory inspection point (GMIP) processes as an area of concern. GMIP inspection and verification requirements are driven by the KSC Ground Operations Quality Planning and Requirements Document and the Marshall Space Flight Center Mandatory Inspection Documents.

NASA IMPLEMENTATION

NASA has chartered an Independent Assessment Team (IAT) made up of experts from NASA, the Department of Defense, the aerospace industry, and the Federal Aviation Administration to evaluate the effectiveness of GMIP verification for the Shuttle Processing Directorate at KSC and the External Tank Project at MAF. The team will emphasize the review of policy and the evaluation of hardware processes associated with selected existing GMIPs. After the assessment is complete, its results, along with their potential effect on return to flight, will be provided to the NASA Offices of Space Flight (OSF) and Safety and Mission Assurance (OSMA), and to the Space Shuttle Program (SSP) for disposition.

To ensure the continued validity of the GMIP process, NASA will systematically audit the inspection criteria.

STATUS

In July 2003, OSF reviewed and approved a draft terms of the reference (TOR) document and the proposed membership for the GMIP's IAT. The Assessment Team was formally selected and chartered through a final TOR, signed by the Cochairs of the Space Flight Leadership Council and the Associate Administrator for OSMA. The team was briefed by, and held discussions with, all levels of management and the safety and mission assurance workforce at KSC and MAF. The team also performed walkdowns and gathered data at both locations.

The results of the IAT's work is consolidated in a report, released in January 2004, containing findings, recommendations, and observations related to GMIP policy, processes, and workforce. The report links recommendations to specific facts and observations made by the team. Preliminary findings, recommendations, and observations have been briefed to OSMA and OSF.

The IAT determined that the NASA Quality Assurance programs in place today are relatively good based on the ground rules that were in effect when the programs were formulated; however, these rules have changed since the programs' formulation. The IAT recommended that NASA reassess its quality assurance requirements based on the modified ground rules established as a result of the *Columbia* accident. The modified ground rules for the Space Shuttle include an acknowledgement that the Space Shuttle is an aging, relatively high risk development vehicle. As a result, the NASA Safety and Mission Assurance Quality Assurance Program must help to ensure both safe hardware and an effective contractor quality program.

The IAT's findings echo the Observations and Recommendations of the CAIB. Among the recommendations the team identified are

- Strengthen the Agency-level policy and guidance to specify the key components of a comprehensive Quality Assurance Program that includes, among other things, the appropriate application of GMIPs
- Establish a formal process for periodic review of QPRD and GMIP requirements at KSC, and the Mandatory Inspection Documents and GMIPs at MAF, against updates to risk management documentation (Hazard Analyses, Failure Modes and Effects Analyses/Critical Item List) and other system changes

- Continue to define and implement formal, flexible processes for changing the QPRD and adding, changing, or deleting GMIPs
- Document and implement a comprehensive Quality Assurance Program at KSC in support of the Space Shuttle Program activities
- Develop and implement a well defined, systematically deployed Quality Assurance Program at MAF

In response to the CAIB Report, the Marshall Space Flight Center (MSFC) and KSC Shuttle Processing Safety and Mission Assurance initiated efforts to address identified Quality Assurance Program shortfalls. The activities under way at KSC include

- A formal process was implemented to revise GMIPs
- A change review board comprised of the Shuttle Processing Chief Engineer, Safety and Mission Assurance, and, as applicable, contractor engineering representatives has been established to disposition proposed changes
- A new process is under development to document and implement temporary GMIPs while permanent GMIP changes are pending, or as deemed necessary for one-time or infrequent activities
- A pilot project was initiated to trend GMIP accept/reject data to enhance first-time quality determination and identify paths for root cause correction
- Surveillance has been increased through additional random inspections for hardware and compliance audits for processes
- Enhanced Quality Inspector training, based on benchmarking similar processes, is under development

In response to the shortfalls identified at MAF, MSFC initiated the following:

- Application of the CAIB observations and the IAT recommendations to all MSFC propulsion elements
- Formalizing and documenting processes that have been in place for Quality Assurance program planning and execution at each manufacturing location
- Increasing the number of inspection points for External Tank assembly
- Increasing the level and scope of vendor audits (process, system, and supplier audits)
- Improving training across the entire MSFC SMA community, with concentration on the staff stationed at manufacturer and vendor resident management offices

To further strengthen the overall Space Shuttle Quality Assurance Program, a new management position has been established and filled on the Shuttle SMA Manager's staff with a specific focus on Quality.

FORWARD WORK

The final IAT report consisting of observations, findings, and recommendations has been provided to the Space Shuttle Program for implementation.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Headquarters	Jul 03 (Complete)	Assessment begun
Headquarters	Oct 03 (Complete)	Presentation to OSF and OSMA
Headquarters	Jan 04 (Complete)	Final report issued
SSP	TBD	Implement changes to the Quality Process identified in the Final Report

Columbia Accident Investigation Board

Observation 10.1-1

NASA should develop and implement a public risk acceptability policy for launch and re-entry of space vehicles and unmanned aircraft.

BACKGROUND

Launch and entry[1] of space vehicles and operation of uncrewed aircraft typically involve substantial hazards, which can pose significant risk to the public and operational personnel. In particular, the *Columbia* accident demonstrated that Orbiter breakup during entry has the potential to cause casualties among the general public. As the lead government agency directing or controlling launch, entry, and other range flight operations, NASA is legally responsible for public safety during all phases of the operations.

NASA and the Air Force maintain agreements that provide for the management of safety risk associated with Shuttle launches. The Air Force 45th Space Wing is responsible for consequences within and outside Federal property resulting from Shuttle launch and ascent. This includes risk assessment, risk mitigation, and acceptance/disposition of residual risk to public and operational personnel. The Director of Kennedy Space Center (KSC) is responsible for consequences and risk mitigation for visitors and mission-essential/nonmission essential personnel on KSC's Federal property. The Air Force provides the Director with written notification of launch area risk estimates for Shuttle ascent. No equivalent collaboration exists between NASA and the Air Force for addressing Orbiter entry and landing risks. For past Orbiter entry operations, NASA has not implemented public risk acceptability standards or a process for managing risk to the public.

NASA does not currently have an Agency risk policy that specifically addresses range flight operations, such as launch and entry of space vehicles and operation of uncrewed aircraft. However, NASA has a more general risk management requirement, codified in NASA Policy Directive (NPD) 8700.1A. This NPD calls for NASA to implement structured risk management processes using qualitative and quantitative risk-assessment techniques to make optimal decisions regarding safety and the likelihood of mission success. The NPD also requires program managers to implement risk management policies, guidelines, and standards and establish safety requirements within their programs. These and other related policies are designed to protect the public as well as NASA personnel and property.

[1]NASA typically uses the term "entry," which is synonymous with the term "re-entry" used in the *Columbia* Accident Investigation Board (CAIB) report.

Individual NASA range safety organizations, such as those at Wallops Flight Facility (WFF) and Dryden Flight Research Center (DFRC), have established public and workforce risk management requirements and processes at the local level. These NASA organizations often work in collaboration with the Air Force and other government range safety organizations. They have extensive experience applying risk assessment to the operation of Expendable Launch Vehicles and uncrewed aircraft and are currently developing range safety approaches for the operation of future Reusable Launch Vehicles, which include launch and entry risk assessment.

NASA IMPLEMENTATION

Development of any Agency policy requires significant coordination with the NASA Centers and programs that will be responsible for its implementation. The NASA Headquarters Office of Safety and Mission Assurance (OSMA) has established a risk policy working group to perform the initial development and coordination on the risk acceptability policy for launch and entry of space vehicles and uncrewed aircraft. This working group hosted a range safety risk management workshop July 24 - 25, 2003, at NASA Headquarters. Working group members in attendance included NASA personnel from KSC, DFRC, WFF, Johnson Space Center (JSC), and Headquarters. Also in attendance were representatives from the CAIB.

Thus far, the working group has received a comprehensive technical briefing on the CAIB-initiated entry risk study that was performed by ACTA Inc., and obtained perspective on the CAIB investigation and recommendations related to assessing public risk from a CAIB Staff Investigator. They have also obtained Agencywide perspective on application of risk assessment to range operations for all current and planned programs (e.g., Shuttle, Expendable Launch Vehicles, Reusable Launch Vehicles, Unmanned Aerial Vehicles, and high-altitude balloons). Building on this information, they have coordinated plans for addressing risk to the public for return to flight (RTF) and for development of NASA range safety risk policy and have begun to draft a proposed NASA risk policy.

The draft policy will be applicable to all range flight operations, including launch and entry of space vehicles and

operation of uncrewed aircraft, and will include requirements for risk assessment, mitigation, and acceptance/disposition of residual risk to the public and operational personnel. It will incorporate performance standards that provide for safety while allowing appropriate flexibility needed to accomplish mission objectives and include acceptable risk criteria that are consistent with those used throughout the government, the commercial range community, and with other industries whose activities are potentially hazardous to the public.

Finally, the policy will provide a risk management process within which the required level of management approval increases as the level of assessed risk to public and the workforce increases and will be flexible enough to allow the fidelity of Program risk assessments to improve over time as knowledge of the vehicle's operational characteristics increases and models used to calculate risk are refined.

The policy document being developed will be a part of a NASA Procedural Requirements (NPR) 8715.XX, NASA Range Safety Program, which will describe NASA's range safety policy, roles and responsibilities, requirements, and procedures for protecting the safety and health of the public, the workforce, and property during range operations. Chapter 3 of this NPR will contain the NASA risk management policy for all range operations including launch and entry of space vehicles and operation of uncrewed vehicles.

STATUS

The draft NPR, including the risk policy, is nearing completion. The NASA Safety and Mission Assurance (SMA) Directors were briefed on the draft NPR on October 15, 2003, with particular focus on the range safety risk policy. The SMA Directors and other members of the NASA SMA community completed a review of the draft NPR in November 2003. The resulting draft is now being readied for entry into the Agency's formal approval process using the NASA Online Directives Information System (NODIS).

FORWARD WORK

The draft risk policy requires that each program documents its safety risk management process in a written plan approved by the responsible NASA official(s). Prior to RTF, the Space Shuttle Program (SSP) will draft its plan and obtain the required Agency approvals. The SSP will also perform launch and entry risk assessments for the initial and subsequent planned Shuttle missions. Launch risk assessment will continue to be performed by the 45th Space Wing in coordination with the Shuttle program and KSC. SSP efforts to assess entry risk are addressed by Space Shuttle Program Action #2.

In accordance with the risk policy and the Space Shuttle safety risk management plan, the appropriate level of NASA management will review and address the assessed risk to the public and the workforce prior to RTF.

SCHEDULE

Enter the resulting draft NPR into the January 2004 NODIS review cycle, which will lead to final signature by the end of April 2004.

Action	January NODIS Review Cycle
Begin SMA Discipline Review	10/30/03 (Complete)
SMA Review Comments Due	11/30/03 (Complete)
Disposition SMA Comments	11/30/03 – 12/22/03 (Complete)
Final Proofread, prepare NODIS Package, route for OSMA Management Signature, provide feedback to SMA Directors	12/22/03 – 1/6/04 (Complete)
Published Deadline for Submission to NODIS	1/16/04 (Complete)
NODIS Review Begins	1/27/04
NODIS Comments Due	2/26/04
Disposition Comments and Prepare Final Package	2/26/04 – 3/11/04
Signature (Purple) Package Due to JM	3/11/04
Signature Package Processing (Legal, Correspondence Control, Code A)	3/11/04 – 4/26/04
Anticipated Final Signature	4/26/04

NOTE: Gray-shaded boxes are hard deadlines

Columbia Accident Investigation Board

Observation 10.4-1

Perform an independently led, bottom-up review of the Kennedy Space Center Quality Planning Requirements Document to address the entire quality assurance program and its administration. This review should include development of a responsive system to add or delete government mandatory inspections.

BACKGROUND

The response to this observation is addressed in detail in Space Shuttle Program Action 1 (SSP-1), Quality Planning and Requirements Document (QPRD)/Government Mandated Inspection Points (GMIPs).

NASA IMPLEMENTATION

The Space Flight Leadership Council and the Associate Administrator for Safety and Mission Assurance, with concurrence from the Safety and Mission Assurance (SMA) Directors at Kennedy Space Center (KSC), Johnson Space Center (JSC), and Marshall Space Flight Center (MSFC), chartered an independent assessment of the Space Shuttle Program GMIPs for KSC Orbiter Processing and Michoud Assembly Facility (MAF) External Tank manufacturing. The Leadership Council also approved the establishment of an assessment team consisting of members from various NASA centers, the Federal Aviation Administration, the U.S. Army, and the U.S. Air Force. This Independent Assessment Team will assess the KSC QPRD and the MAF Mandatory Inspection Document criteria, their associated quality assurance processes, and the organizations that perform them. The team has already performed site visits, held discussions with Safety and Mission Assurance personnel, and conducted interim discussions with representatives at both KSC and MAF. The team is developing findings, recommendations, and observations. A draft report will be provided to the sponsoring organizations for review and comment. After resolving issues, a final report will be issued. Recommendations will become formal Space Shuttle Program actions. This report will be used as a basis for the Program to evaluate similar GMIP activity at other Space Shuttle manufacturing and processing locations.

In parallel with the Independent Assessment Team's (IAT) review, a new process to make changes to GMIP requirements has been developed, approved, and baselined at KSC. This process ensures that anyone can submit a proposed GMIP change, and that the initiator who requests a change receives notification of the disposition of the request and the associated rationale. That effort was completed with the release of KSC procedural document P-1822. This process will use a database for tracking the change proposal, the review team's recommendations and the Change Board's decisions. The database automatically notifies the requester of the decision, and the process establishes a means to appeal decisions. Additional changes to the process will be based in part on the results of the IAT's review.

STATUS

The IAT determined that the NASA Quality Assurance programs in place today are relatively good based on the ground rules that were in effect when the programs were formulated; however, these rules have changes since the program's formulation. The IAT recommended that NASA reassess its quality assurance requirements based on the modified ground rules established as a result of the *Columbia* accident. The modified ground rules for the Space Shuttle include an acknowledgement that the Space Shuttle is an aging, relatively high risk development vehicle. As a result, the NASA Safety and Mission Assurance Quality Assurance Program must help to ensure both safe hardware and an effective contractor quality program.

The IAT's findings echo the Observations and Recommendations of the CAIB. Among the recommendations the team identified are

- Strengthen the Agency-level policy and guidance to specify the key components of a comprehensive Quality Assurance Program that includes, among other things, the appropriate application of GMIPs

- Establish a formal process for periodic review of QPRD and GMIP requirements at KSC, and the Mandatory Inspection Documents and GMIPs at MAF, against updates to risk management documentation (Hazard Analyses, Failure Modes and Effects Analyses/Critical Item List) and other system changes
- Continue to define and implement formal, flexible processes for changing the QPRD and adding, changing, or deleting GMIPs
- Document and implement a comprehensive Quality Assurance Program at KSC in support of the Space Shuttle Program activities
- Develop and implement a well defined, systematically deployed Quality Assurance Program at MAF

In response to the CAIB Report, Marshall Space Flight Center (MSFC) and KSC Shuttle Processing Safety and Mission Assurance initiated efforts to address the identified Quality Assurance Program shortfalls. The activities under way at KSC include

- A formal process was implemented to revise GMIPs
- A change review board comprised of the Shuttle Processing Chief Engineer, Safety and Mission Assurance, and, as applicable, contractor engineering representatives has been established to disposition proposed changes
- A new process is under development to document and to implement temporary GMIPs while permanent GMIP changes are pending, or as deemed necessary for one-time or infrequent activities
- A pilot project was initiated to trend GMIP accept/reject data to enhance first-time quality determination and identify paths for root cause correction
- Surveillance has been increased through additional random inspections for hardware and compliance audits for processes
- Enhanced Quality Inspector training, based on benchmarking similar processes, is under development

In response to the shortfalls identified at MAF, MSFC initiated the following:

- Applying CAIB observations and the IAT recommendations to all MSFC propulsion elements
- Formalizing and documenting processes that have been in place for Quality Assurance program planning and execution at each manufacturing location
- Increasing the number of inspection points for External Tank assembly
- Increasing the level and scope of vendor audits (process, system, and supplier audits)
- Improving training across the entire MSFC SMA community, with concentration on the staff stationed at manufacturer and vendor resident management offices

To further strengthen the overall Space Shuttle Quality Assurance Program, a new management position has been established and filled on the Shuttle SMA Manager's staff with a specific focus on Quality.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
NASA HQ	Oct 03 (Complete)	Report out from IAT
NASA HQ	Jan 04 (Complete)	Publish the IAT report

Columbia Accident Investigation Board

Observation 10.10-1

NASA should reinstate a safety factor of 1.4 for the Attachment Rings – which invalidates the use of ring serial numbers 16 and 15 in their present state – and replace all deficient material in the Attachment Rings.

BACKGROUND

The External Tank Attach (ETA) rings are located on the Solid Rocket Boosters (SRBs) on the forward end of the aft motor segment (figure 10.10-1-1). The rings provide the aft attach points for the SRBs to the External Tank (ET). Approximately two minutes after liftoff, the SRBs separate from the Shuttle vehicle.

In late 2002, Marshall Space Flight Center (MSFC) engineers were performing tensile tests on ETA ring web material prior to the launch of STS-107 and discovered the ETA ring material strengths were lower than the design requirement. The ring material was from a previously flown and subsequently scrapped ETA ring representative of current flight inventory material. A one-time waiver was granted for the STS-107 launch based on an evaluation of the structural strength factor of safety requirement for the ring of 1.4 and adequate fracture mechanics safe-life at launch. The most probable cause for the low strength material was an off-nominal heat treatment process. Following SRB retrieval, the STS-107 rings were inspected as a normal part of postflight inspection, and no issues were identified with flight performance.

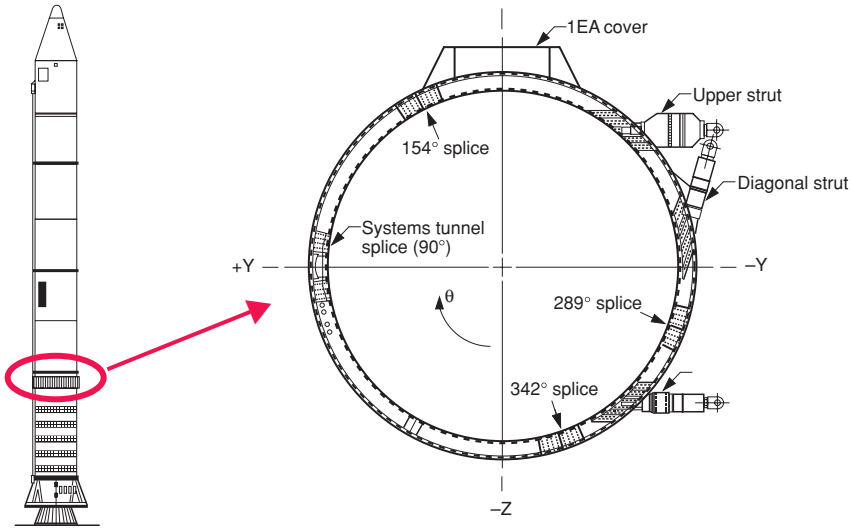


Figure O10.10-1-1. ETA ring location.

NASA IMPLEMENTATION

NASA will use a nonlinear analysis method to ensure the rings meet program strength requirements for a factor of safety of 1.4 or greater. The nonlinear analysis method is a well established technique employed throughout the aerospace industry that addresses the entire material stress-strain response and more accurately represents the material's ultimate strength capability by allowing load redistribution. Nonlinear analysis demonstrates that all ETA ring hardware meets program strength requirements.

NASA will update the strength and fracture analysis for the ETA rings. Fracture mechanics analysis will determine the minimum mission life for the rings and define the necessary inspection interval. NASA will use testing, inspection, and analyses of flight hardware to fully characterize the material for each of the ETA rings in the Shuttle Program inventory. This will provide added assurance that the flight hardware meets Shuttle Program requirements and continues to have an adequate margin for safety above the 1.4 factor of safety requirement.

STATUS

The SRB Project has developed and verified by test (figure O10.10-1-2) a nonlinear analysis approach.

Hardware materials characterization includes ring web thickness measurements and hardness testing (figure O10.10-1-3) of the splice plates and ring webs. Serial number 15 and 16 ETA rings have exhibited unacceptable material variability as noted by hardness measurements and thus are being set aside as the initial candidates for

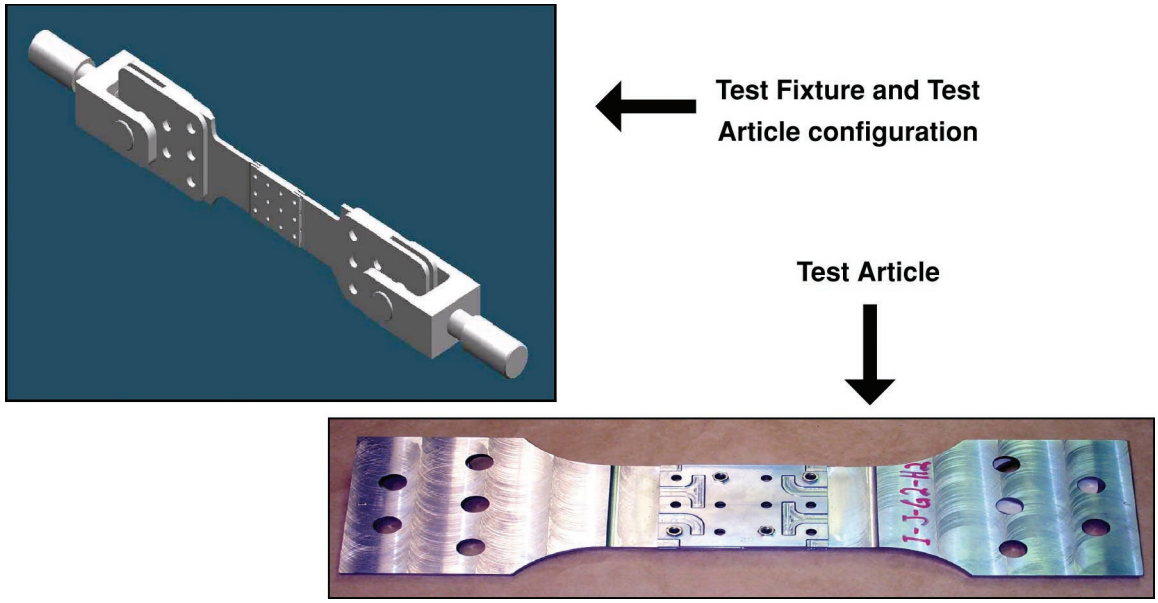


Figure O10.10-1-2. Test articles.

upgrade/replacement. Any other rings that exhibit similarly unacceptable material or high variability in the hardness measurements will also be set aside for upgrade or replacement. Fracture Control Plan requirements compliance will be ensured by performing extensive nondestructive inspections (NDI) to rebaseline all areas of the ETA ring hardware.

Hardware inspections for the first flight set of ETA rings are complete with no reportable indications noted and all areas of the rings meeting factor of safety requirements. Final safe life assessment is pending fracture property testing, which is scheduled for completion the end of January 2004. Processing of the second ETA ring flight set is under way.

Figure O10.10-1-3. Harness testing.

FORWARD WORK

Hardware inspections for each of the remaining ETA rings in the Space Shuttle Program inventory are continuing. A recommendation is being considered to replace the current ETA rings and impose the appropriate material property verification and NDI requirements. A decision package, including certification plans, is forthcoming.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SRB Project	Feb 04	First flight set ETA rings complete
SRB Project	Feb 04	New ring procurement package
SRB Project	Jan 06	Delivery of first new ETA ring

As a member of the Apollo Spacecraft Program's Systems Engineering and Integration Office, he developed the Spacecraft Operations Data Book system that documented systems and subsystem performance and was the control database for developing flight rules, crew procedures, and overall performance of the Apollo spacecraft.

After Apollo, he became Manager of System Integration for the Space Shuttle Program; Deputy Manager, Space Shuttle Program; and then Deputy Director of the Space Shuttle Program at JSC. As Deputy Director, he was responsible for the daily engineering, processing, and operations activities of the Shuttle Program, and he developed an extensive background in Shuttle systems integration. In 1989, he became the Director of Space Station Freedom, with overall responsibility for its development and operation.

After years of public service, he left NASA to become the Director of the ANSER Center for International Aerospace Cooperation (1994–1997). Mr. Kohrs joined Kistler Aerospace in 1997 as Chief Engineer. His primary responsibilities include vehicle integration, design specifications, design data books, interface control, vehicle weight, performance, and engineering review board matters. He received a Bachelor of Science degree from Washington University, St. Louis, in 1956.

Susan Morrissey Livingstone:

Susan Livingstone has served her nation for more than 30 years in both Government and civic roles. From July 2001–February 2003, she served as Under Secretary of the Navy. As "COO" to the Secretary of the Navy, she had a broad executive management portfolio (e.g., programming, planning, budgeting, business processes, organizational alignment), but also focused on Naval space, information technology, and intelligence/compartmented programs; integration of Navy-Marine Corps capabilities; audit, Inspector General and criminal investigative programs; and civilian personnel programs.

Ms. Livingstone is a policy and management consultant and also serves as a member of the National Security Studies Board of Advisors (Maxwell School, Syracuse University), is a board member of the Procurement Round Table, and was appointed to NASA's Return to Flight Task Group for safe return of Shuttle flight operations.

Prior to serving as Under Secretary of the Navy, she was CEO of the Association of the United States Army and deputy chairman of its Council of Trustees. She also served as a vice president and board member of the Procurement Round Table, and as a consultant and panel chairman to the Defense Science Board (on "logistics transformation").

From 1993 to 1998, Ms. Livingstone served the American Red Cross Headquarters as Vice President of Health and Safety Services, Acting Senior Vice President for Chapter Services, and a consultant for Armed Forces Emergency Services.

As Assistant Secretary of the Army for Installations, Logistics and Environment from 1989 to 1993, she was responsible for a wide range of programs including military construction, installation management, Army logistics programs, base realignment and closures, energy and environmental issues, domestic disaster relief, and restoration of public infrastructure to the people of Kuwait following operation Desert Storm. She also was decision and acquisition management authority for the DOD chemical warfare materiel destruction program.

From 1981 to 1989, Ms. Livingstone served at the Veterans Administration (VA) in a number of positions including Associate Deputy Administrator for Logistics and Associate Deputy Administrator for Management. She served as the VA's Senior Acquisition Official and also directed and managed the Nation's largest medical construction program. Prior to her Executive Branch service, she worked for more than nine years in the Legislative branch on the personal staffs of both a Senator and two congressmen.

Ms. Livingstone graduated from the College of William and Mary in 1968 with an a Bachelor of Arts degree and completed a Master of Arts in political science at the University of Montana in 1972. She also spent two years in postgraduate studies at Tufts University and the Fletcher School of Law and Diplomacy.

Livingstone has received numerous awards for her community and national service, including the highest civilian awards from the NRO, VA, and the Departments of the Army and Navy. She is also a recipient of the Secretary of Defense Award for Outstanding Public Service.

Mr. James D. Lloyd:
Deputy Associate Administrator for Safety and Mission Assurance, NASA

Ex-Officio Member

Mr. Lloyd has extensive experience in safety engineering and risk management, and has supported a number of Blue Ribbon panels relating to mishaps and safety problems throughout his career. He began his career after an intern training period as a system safety engineer with the U.S. Army Aviation Systems Command in St. Louis.

He transferred to its parent headquarters, the Army Materiel Command (AMC) in 1973 and, after serving several safety engineering roles, was appointed as the Chief of the Program Evaluation Division in the Command's Safety Office, where he assured the adequacy of safety programs for AMC organizations.

In 1979, he continued his career as a civilian engineer with the AMC Field Safety Activity in Charlestown, IN, where he directed worldwide safety engineering, evaluation, and training support. In 1987, a year after the Shuttle Challenger disaster, Mr. Lloyd transferred from the U.S. Army to NASA to help the Agency rebuild its safety mission assurance program. He was instrumental in fulfilling several of the recommendations issued by the Rogers' Commission, which investigated the *Challenger* mishap. After the Shuttle returned to flight with the mission of STS-26, Mr. Lloyd moved to the Space Station Freedom Program Office in Reston, Va., where he served in various roles culminating in being appointed as the Program's Product Assurance Manager.

In 1993, he became Director, Safety and Risk Management Division in the Office of Safety and Mission Assurance, serving as NASA's "Safety Director" and was appointed to his present position in early 2003. He serves also as an ex-officio member of the NASA Advisory Council Task Force on ISS Operational Readiness. Lloyd holds a Bachelor of Science degree in Mechanical Engineering, with honors, from Union College, Schenectady, N.Y., and a Master of Engineering degree in Industrial Engineering from Texas A&M University, College Station.

Lt. Gen. Forrest S. McCartney, U.S. Air Force (Ret.):
Vice Chairman of the Aerospace Safety Advisory Panel

During Lt. Gen. McCartney's distinguished Air Force career, he held the position of program director for several major satellite programs, was Commander of the Ballistic Missile Organization (responsible for Minuteman and Peacekeeper development), Commander of Air Force Space Division, and Vice Commander, Air Force Space Command.

His military decorations and awards include the Distinguished Service Medal, Legion of Merit with one oak leaf cluster, Meritorious Service Medal, and Air Force Commendation Medal with three oak leaf clusters. He was recipient of the General Thomas D. White Space Trophy in 1984 and the 1987 Military Astronautical Trophy.

Following the *Challenger* accident, in late 1986 Lt. Gen. McCartney was assigned by the Air Force to NASA and served as the Director of Kennedy Space Center until 1992. He received numerous awards, including NASA's Distinguished Service Medal and Presidential Rank Award, the National Space Club Goddard Memorial Trophy, and AIAA Von Braun Award for Excellence in Space Program Management.

After 40 years of military and civil service, he became a consultant to industry, specializing in the evaluation of hardware failure/flight readiness. In 1994, he joined Lockheed Martin as the Astronautics Vice President for Launch Operations. He retired from Lockheed Martin in 2001 and is currently the Vice Chairman of the NASA Aerospace Safety Advisory Panel.

Lt. Gen. McCartney has a Bachelor's degree in Electrical Engineering from Auburn University, a Master's degree in Nuclear Engineering from the Air Force Institute of Technology, and an honorary doctorate from the Florida Institute of Technology.

Rosemary O'Leary J.D., Ph.D.:

Dr. Rosemary O'Leary is professor of public administration and political science, and coordinator of the Ph.D. program in Public Administration at the Maxwell School of Citizenship and Public Affairs at Syracuse University. An elected member of the U.S. National Academy of Public Administration, she was recently a senior Fulbright scholar in Malaysia. Previously Dr. O'Leary was Professor of Public and Environmental Affairs at Indiana University and cofounder and codirector of the Indiana Conflict Resolution Institute. She has served as the Director of Policy and Planning for a state environmental agency and has worked as an environmental attorney.

Dr. O'Leary teaches graduate courses in Public Organizations and Management, concentrating on organization change, organization culture, and the management of scientific and technical organizations.

She was a consultant to the U.S. Department of the Interior, the U.S. Environmental Protection Agency, the Indiana Department of Environmental Management, the International City/County Management Association, the National Science Foundation, and the National Academy of Sciences.

Dr. O'Leary is the author or editor of five books and more than 75 articles on public management. She has won seven national research awards, including Best Book in Public and Nonprofit Management for 2000 (given by the Academy of Management), Best Book in Environmental Management and Policy for 1999 (given by the American Society for Public Administration), and the Mosher Award, which she won twice, for best article by an academician published in Public Administration Review.

Dr. O'Leary was recently awarded the Syracuse University Chancellor's Citation for Exceptional Academic Achievement, the highest research award at the university. She has won eight teaching awards as well, including the national Excellence in Teaching Award given by the National Association of Schools of Public Affairs and Administration, and she was the recipient of the Distinguished Service Award given by the American Society for Public Administration's Section on Environment and Natural Resources Administration. O'Leary has served as national chair of the Public Administration Section of the American Political Science Association, and as the national chair of the Section on Environment and Natural Resources Administration of the American Society for Public Administration.

Dr. Decatur B. Rogers, P.E.,

Dean Tennessee State University College of Engineering, Technology and Computer Science

Since 1988, Dr. Rogers has served as the Dean, College of Engineering, Technology and Computer Science, and Professor of Mechanical Engineering at Tennessee State University in Nashville. Rogers served in professorship and dean positions at Florida State University, Tallahassee; Prairie View A&M University, Prairie View, Texas; and Federal City College, Washington, D.C.

Dr. Rogers holds a Ph.D. in Mechanical Engineering from Vanderbilt University; Masters' degrees in Engineering Management and Mechanical Engineering from Vanderbilt University; and a Bachelor's in Mechanical Engineering from Tennessee State University.

Mr. Sy Rubenstein:

Aerospace Consultant

Mr. Rubenstein was a major contributor to the design, development, and operation of the Space Shuttle and has been involved in commercial and Government projects for more than 35 years. As an employee of Rockwell International, the prime contractor for the Shuttle, he was the Director of System Engineering, Chief Engineer, Program Manager, and Division President during 20 years of space programs.

He has received the NASA Public Service Medal, the NASA Medal for Exceptional Engineering, and the AIAA Space Systems Award for his contributions to human spacecraft development. Mr. Rubenstein, a leader, innovator, and problem solver, is a fellow of the AIAA and the AAS.

Mr. Robert Sieck:

Aerospace Consultant

Mr. Sieck, the former Director of Shuttle Processing at the Kennedy Space Center (KSC), has an extensive background in Shuttle systems, testing, launch, landing, and processing. He joined NASA in 1964 as a Gemini Spacecraft Systems engineer and then served as an Apollo Spacecraft test team project engineer. He later became the Shuttle Orbiter test team project engineer, and in 1976 was named the Engineering Manager for the Shuttle Approach and Landing Tests at Dryden Flight Research Facility in California. He was the Chief Shuttle Project Engineer for STS-1 through STS-7, and became the first KSC Shuttle Flow Director in 1983. He was appointed Director, Launch and Landing Operations, in 1984, where he served as Shuttle Launch Director for 11 missions.

He served as Deputy Director of Shuttle Operations from 1992 until January 1995 and was responsible for assisting with the management and technical direction of the Shuttle Program at KSC. He also retained his position as Shuttle Launch Director, a responsibility he had held from February 1984 through August 1985, and then from December 1986 to January 1995. He was Launch Director for STS-26R and all subsequent Shuttle missions through STS-63. Mr. Sieck served as Launch Director for 52 Space Shuttle launches.

He earned his Bachelor of Science degree in Electrical Engineering at the University of Virginia in 1960 and

obtained additional postgraduate credits in mathematics, physics, meteorology, and management at both Texas A&M and the Florida Institute of Technology. He has received numerous NASA and industry commendations, including the NASA Exceptional Service Medal and the NASA Distinguished Service Medal. Mr. Sieck joined the Aerospace Safety Advisory Panel as a consultant in March 1999.

Lt. Gen. Thomas Stafford, U.S. Air Force (Ret.):

Cochair, Return to Flight Task Group

President, Stafford, Burke and Hecker Inc., technical consulting

Lt. Gen. Stafford, an honors graduate of the U.S. Naval Academy, joined the space program in 1962 and flew four missions during the Gemini and Apollo programs. He piloted Gemini 6 and Gemini 9, and traveled to the Moon as Commander of Apollo 10. He was assigned as head of the astronaut group in June 1969, responsible for the selection of flight crews for projects Apollo and Skylab.

In 1971, Lt. Gen. Stafford was assigned as Deputy Director of Flight Crew Operations at the NASA Manned Spacecraft Center. His last mission, the Apollo-Soyuz Test Project in 1975, achieved the first rendezvous between American and Soviet spacecrafts.

He left NASA in 1975 to head the Air Force Test Flight Center at Edwards Air Force Base and, in 1978, assumed duties as Deputy Chief of Staff, Research Development and Acquisition, U.S. Air Force Headquarters in Washington. He retired from government service in 1979 and became an aerospace consultant.

Lt. Gen. Stafford has served as Defense Advisor to former President Ronald Reagan; and headed The Synthesis Group, which was tasked with plotting the U.S. return to the Moon and eventual journey to Mars.

Throughout his careers in the Air Force and NASA space program, he has received many awards and medals including the Congressional Space Medal of Honor in 1993. He served on the National Research Council's Aeronautics and Space Engineering Board, the Committee on NASA Scientific and Technological Program Reviews, and the Space Policy Advisory Council.

He was Chairman of the NASA Advisory Council Task Force on Shuttle-Mir Rendezvous and Docking Missions. He is currently the Chairman of the NASA Advisory Council Task Force on International Space Station Operational Readiness.

Mr. Tom Tate:

Mr. Tate was vice president of legislative affairs for the Aerospace Industries Association (AIA), the trade association representing the nation's manufacturers of commercial, military, and business aircraft, helicopters, aircraft engines, missiles, spacecraft, and related components and equipment. Joining AIA in 1988, Tate directs the activities of the association's Office of Legislative Affairs, which monitors policy issues affecting the industry and prepares testimony that communicates the industry's viewpoint to Congress.

Before joining AIA, Tate served on the staff of the House of Representative's Committee on Science and Technology for 14 years. Joining the staff in 1973 as a technical consultant and counsel to the House Subcommittee on Space Science and Applications, he was appointed deputy staff director of the House Subcommittee on Energy Research and Development in 1976. In 1978, Tate returned to the space subcommittee as chief counsel; and in 1981, he became special assistant to the chairman of the committee until joining AIA.

Mr. Tate worked for the Space Division of Rockwell International in Downey, Calif., from 1962 to 1973 in various engineering and marketing capacities and was director of space operations when he departed the company in 1973. He worked on numerous programs, including the Gemini Paraglider, Apollo, Apollo/Soyuz, and Shuttle Programs.

Mr. Tate worked for RCA's Missile and Surface Radar Division in Moorestown, N.J. from 1958 to 1962 in the project office of the Ballistic Missile Early Warning System (BMEWS) being built for the USAF. From 1957 to 1958, Tate served in the Army as an artillery and guided missile officer at Fort Bliss, Texas.

He received a Bachelor's degree in marketing from the University of Scranton in 1956 and a law degree from Western State University College of Law in Fullerton, Calif., in 1970. In his final year of law school, his fellow students awarded him the Gold Book Award as the most outstanding student. In 1991, he received the Frank J. O'Hara award for distinguished alumni in science and technology from the University of Scranton.