March 18, 2005
Volume 1, Ninth Edition

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

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

Ninth Edition Summary
March 18, 2005

This revision *to NASA's Implementation Plan for Space Shuttle Return to Flight and Beyond* updates several critical areas in our return to flight (RTF) efforts. These include Thermal Protection System (TPS) repair, inspection, and testing; External Tank (ET) modifications and verification; and vehicle health information. In addition, NASA completed a new Program-level Contingency Action Plan for Space Shuttle Operations and exercised new mission management team processes through an end-to-end simulation that included new Space Shuttle imaging capabilities and on-orbit TPS inspections.

The Space Shuttle Program has established the Development Test Objective (DTO) for TPS repair on flights STS-114 and STS-121. The DTO will include flying simulated tile and Reinforced Carbon-Carbon (RCC) damage in the payload bay of the Shuttle to enable the Shuttle crew to practice repair techniques. On STS-114, the crew will perform an extravehicular activity to test and evaluate the tile repair emittance wash application and the RCC crack repair material. The crew will also do an in-cabin demonstration of the mechanical aspects of RCC plug repair.

NASA has also succeeded in establishing preliminary impact and damage tolerance thresholds for both foam and ice against both tile and RCC. These impact tolerance thresholds are the levels at which detectable damage begins to occur. The thresholds have been provided to the Program for risk assessment of the TPS capability against the expected debris environment. The results of this assessment will be available in March–April 2005. Test and analysis indicates that the RCC's ability to withstand damage varies considerably among the panels and surface location because of different areas of structural criticality and heating profiles during entry. Tests indicate that in the most sensitive areas, the RCC cannot safely tolerate significant areas of lost coating. However, the same damage in areas of lower heating are likely not critical. These impact and damage tolerance data are helping to determine the Space Shuttle Program approach to inspecting the TPS during the first two missions, including requirements for the functionality of the sensors. In preparation for RTF, the Orbiter Project is making progress on certifying the Orbiter Boom and its sensors for flight on STS-114.

NASA has also completed the ET bipod fitting redesign verification. NASA has determined that, if liberated, the ice at the aft two bellows locations (Station 1979 and Station 2026) would not impact the Orbiter RCC; therefore, no additional action is required for those locations. The closeout for the tank that will fly on STS-114 was applied using a verified and validated TPS application process. During production of this ET flange closeout (and all subsequent flange closeouts), a series of high-fidelity production test articles was used to demonstrate the application on the flight hardware. The acceptability of the closeout was verified through a series of mechanical property tests and dissection of the foam to determine process performance.

Finally, to increase our real-time insight into the Orbiter's operations, beginning with STS-121, the Orbiter will have the capability to downlink low-rate Modular Auxiliary Data System digital data while on orbit. This will enhance Mission Control's insight into the vehicle's health and operational status.

NASA has also made progress working with the Return to Flight Task Group toward closing out the *Columbia* Accident Investigation Board's RTF actions. NASA closed seven of the 15 RTF recommendations: 4.2-3, Two-Person Closeouts; 3.3-1, Structural Integrity of RCC; 4.2-5, Foreign Object Debris; 3.4-2, High-Resolution Images of the External Tank; 4.2-1 Bolt Catchers; 10.3-1, Engineering Drawings; and 6.3-2, Use of National Assets. The Task Group also conditionally closed Recommendation 3.4-1, Three Useful Views of Shuttle Ascent. The remaining RTF actions will be presented to the Task Group over the next several months.

This revision also includes a new introductory section, which replaces the original Return to Flight Summary Overview. The new section addresses NASA and the Space Shuttle Program's approach to risk as it relates to RTF. The Return to Flight Summary Overview will be retained in the document as Appendix C. In addition, this edition begins a new numbering system for revisions to the *Implementation Plan*. Rather than numbering the revisions by major updates, with sub-numbers for page change updates, all revisions to the plan will be numbered sequentially. As a result, this edition is being called the Ninth Edition rather than Revision 3.1. This change should make tracking the revisions simpler.

Following is a list of sections affected by this revision:

Message from Frederick D. Gregory
Return to Flight Cost Summary
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- 3.2-1 External Tank Thermal Protection System Modifications [RTF]
- 3.3-2 Orbiter Hardening [RTF]
- 6.4-1 Thermal Protection System On-Orbit Inspect and Repair [RTF]
- 3.4-1 Ground-Based Imagery [RTF]
- 3.4-2 External Tank Separation Imagery [RTF]
- 3.4-3 On-Vehicle Ascent Imagery [RTF]
- 6.3-2 National Imagery and Mapping Agency Memorandum of Agreement [RTF]
- 3.6-1 Update Modular Auxiliary Data Systems
- 3.6-2 Modular Auxiliary Data System Redesign
- 4.2-2 Enhance Wiring Inspection Capability
- 4.2-1 Solid Rocket Booster Bolt Catcher [RTF]
- 4.2-3 Closeout Inspection [RTF]
- 4.2-4 Micrometeoroid and Orbital Debris Risk
- 4.2-5 Foreign Object Debris Processes [RTF]
- 6.3-1 Mission Management Team Improvements [RTF]
- 9.1-1 Detailed Plan for Organizational Changes [RTF]
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Part 2 – Raising the Bar – Other Corrective Actions
- 2.1 – Space Shuttle Program Actions
  - SSP-2 Public Risk of Overflight
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  - O10.1-1 Public Risk Policy
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2.3 – CAIB Report, Volume II, Appendix D.a
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Message From Frederick D. Gregory

NASA is fast approaching a major milestone in our human space flight program, a milestone that is our first step in implementing the Vision for Space Exploration. When we return the Space Shuttle to flight in May 2005, we will be doing more than lighting up the engines and launching the *Discovery* on her way—we will be demonstrating to the nation and to the world that we are heeding the lessons learned from the loss of the Space Shuttle *Columbia* and her crew. We are showing our willingness to make hard choices and to challenge ourselves to be better and safer than we have ever been before. We are saying that now we are ready for the challenges that we know lay before us as we complete the assembly of the International Space Station and begin to send humans once more beyond low Earth orbit, to the Moon, and eventually to Mars.

In this, our ninth report on our progress for implementing the recommendations and observations of the *Columbia* Accident Investigation Board, we demonstrate our readiness to return safely to flight. We continue to keep the lessons of the *Columbia* always before us: human space flight is risky, but we must always consider the safety of the public, our crews, and our valuable national assets before any other concern. We must continue to challenge our assumptions. It is the benefits derived and national objectives achieved that make us willing as a Nation and an Agency to accept the risks inherent in human space flight.

We are committed to safely returning to flight and safely flying the Space Shuttle fleet until its retirement in 2010. To do less would diminish the life-long contributions of the STS-107 crew and our astronauts who follow in their path. We are mindful that our job is to push the envelope of what is possible. Because of that, we know that the Shuttle and the vehicles that will follow it are developmental vehicles and each flight will be, at least in part, a test flight, a new opportunity to further broaden and deepen our understanding of human space flight.

Returning to flight is not an end to our efforts; it is only the beginning.

Frederick D. Gregory

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The Integrated Accepted Risk Approach for Return to Flight

NASA has come a long way in our journey to make the Space Shuttle system safer. The External Tank bipod Thermal Protection System has been redesigned to eliminate the proximate cause of the *Columbia* accident. In all areas, we have applied the collective knowledge and capabilities of our nation to comply with the *Columbia* Accident Investigation Board recommendations and to raise the bar beyond that. We have taken prudent technical action on potential threats to review and verify the material condition of all critical areas where failure could result in catastrophic loss of the crew and vehicle. We are satisfied that critical systems and elements will operate as intended—safely and reliably. While we will never eliminate all the risks from our human space flight programs, we have eliminated those we can and mitigated others. The remaining identified risks will be evaluated for acceptance.

Our approach to launching, operating on orbit, and safely returning the Space Shuttle *Discovery* to flight on the planned STS-114 mission is based on a rigorous process to achieve the capabilities and reach the milestones needed to meet our objectives. We know that greater capabilities may be achievable with more time and resources; however, the primary Space Shuttle mission is to assemble and support the ongoing operation of the International Space Station. The missions and risks of the International Space Station and Space Shuttle are, for the near term, inseparable. As we look forward to the limited launch window opportunities in 2005, it is reasonable to ask ourselves if the Shuttle is safe enough. Although we will never eliminate all the risks from our Space Shuttle missions, we are confident that we have eliminated those that constituted the proximate cause of the *Columbia* loss. In addition, we have mitigated other risks to a great extent, including engineering, operational, and programmatic risks. We acknowledge that there is more to be done over the long haul to further reduce risk, but the marginal risk return is getting smaller and smaller. With deliberate forethought, we now choose to assess the risk associated with the achievable capabilities consistent with the Spring 2005 launch window. Before we commit to launching the STS-114 mission, we will assure that the residual risk is at an acceptable level to safely return to flight. If we collectively decide that the Space Shuttle is not safe enough for a Spring 2005 return to flight, we will continue to work those technical issues that will improve the risk posture until it is safe enough.

Our risk reduction approach has its roots in the long-standing system safety engineering hierarchy for hazard abatement, which has been employed in the Space Shuttle Program since its inception. The components of the hierarchy are, in order of precedence, to: design for minimum risk by eliminating the hazard through design/redesign; incorporate safety devices through verifiable hazard controls; provide warning devices; or, lastly, establish special procedures and training. This proven approach to risk reduction guides us through the technical challenges, failures, and successes present in our return to flight endeavors. Our approach also provides the structured deliberation process required to form the foundation for accepting residual risk by Program Senior Management.

Space flight and operations are endeavors that could not be undertaken without accepting a high level of risk. Throughout history, humans have accepted risk to achieve the great rewards that exploration offers. Many have bravely faced the hazards and dangers of exploration and failed. NASA has had many more successes than failures and makes every attempt to learn as much as possible from our failures before continuing on. We choose to continue space exploration as an endeavor that is worthy of the risks to achieve our mission, to acquire the ultimate rewards, and to expand our knowledge of the universe. Accepting risk is not taken lightly.

Within the Space Shuttle Program, our system safety engineering hierarchy for hazard abatement requires that we understand and document how we dealt with identified hazards. Hazards that have been eliminated through design by completely removing the hazard causal factors are documented as eliminated. Hazards that cannot be eliminated can be considered controlled when we can demonstrate that the frequency of occurrence or consequence has been reduced through the hazard reduction precedence sequence discussed above so that it is unlikely to occur during the life of the Program. Where identified hazards cannot be eliminated or where controls of the hazard causes have limitations or uncertainties such that the hazard could occur in the life of the Program, Program Management may, after considering all engineering data and opinions, accept the risk.

Return to Flight Requirements

Our top-level requirement for debris is the same as it was before *Columbia*: "*The SSS [Space Shuttle System], including the ground systems, shall be designed to preclude the shedding of ice and/or other debris from the Shuttle elements during prelaunch and flight operations that would jeopardize the flight crew, vehicle, mission success, or would adversely impact turnaround operations.*" The *Columbia* Accident Investigation Board determined that the primary cause of the loss of *Columbia* was the loss of the Thermal Protection System foam from the External Tank bipod that struck the Reinforced Carbon-Carbon panel on *Columbia's* left wing leading edge. Loss of foam was not an isolated incident. Over the life of the Shuttle Program there were several cases of foam loss from the left-hand bipod and other areas of the External Tank. Since *Columbia*, we have initiated a comprehensive test and analysis program to better characterize the potential for External Tank foam loss, to understand the transport mechanisms that move liberated debris to the Orbiter, and to gain knowledge of the capabilities of the Orbiter Thermal Protection System tile and Reinforced Carbon-Carbon elements to withstand impact. From this effort, requirements for allowable debris for given sources have been established to protect the Orbiter elements from critical impact.

Design for Minimum Risk

The External Tank bipod Thermal Protection System has been re-designed to reduce the potential for loss of foam that led to the *Columbia* accident. Our far-reaching initiative to eliminate or reduce the potential for generation of critical debris has led us to the most comprehensive understanding of the overall Space Shuttle system in the history of the Program. We have identified and examined all debris sources and, where necessary, initiated redesign efforts to reduce the potential for debris formation and liberation. There are four primary areas identified on the External Tank for evaluation and redesign to reduce or eliminate the potential for critical debris generation: the bipod foam, the liquid oxygen feedline bellows ice formation, the liquid hydrogen intertank flange foam closeout, and the protuberance air load foam ramps. All have been addressed with respect to the Orbiter debris damage tolerance capabilities and will be verified for flight. In addition to the External Tank, we have assessed the Solid Rocket Booster separation motor plumes and Thermal Protection System elements, as well as potential Orbiter debris sources, such as thruster plumes and butcher paper covers. In the forward portion of the Orbiter, butcher paper that was previously used to cover thruster nozzles to prevent rain from entering prior to launch is being replaced with a less dense material that will reduce the potential for damage to the windows. Our solid rocket bolt catcher system has been redesigned to eliminate a potential failure point, the housing weld, and has been tested and proven to meet design requirements.

Incorporate Safety Devices/Hazard Controls

Although redesigning the External Tank Thermal Protection System to reduce the potential for critical foam loss is our primary goal, we have crafted a wide-ranging approach for reducing the overall risk of operating the Space Shuttle system. Through tests and analysis, we have a new understanding of the potential sources and size of debris that might be present during ascent. We have a new understanding of the capability of the Orbiter Thermal Protection System to withstand debris hits in all flight regimes. A comprehensive test program forms the basis for our newly developed debris transport analysis, providing improved knowledge of the multitude of paths debris might travel to impact the Orbiter, and forming the basis for a validated computerized model for future near-real-time evaluation. Elimination of all critical debris is not attainable; we acknowledge this as fact and accept the remaining risk for return to flight. Improved nondestructive evaluation capabilities will provide greater knowledge of the condition of the External Tank foam in critical areas and the integrity of Orbiter Reinforced Carbon-Carbon parts prior to launch. Although a dramatic improvement, these capabilities use the best available technology to provide a view of what is beneath the surface, but will not allow us to verify the precise conditions of foam and Reinforced Carbon-Carbon elements. We accept the risk associated with the limitations of our available nondestructive evaluation capabilities.

Our fundamental return to flight rationale assumes that the necessary reduction in risk of ascent debris damage will be accomplished primarily through modifications to the External Tank to reduce critical debris liberation during ascent. In addition, we formed an Orbiter Hardening Team to identify options for near-term Thermal Protection System improvements in critical locations. The Orbiter hardening options are being implemented in three phases. Four projects were identified as Phase I, based on maturity of design and schedule for implementation, and will be implemented before return to flight. These include: front spar “sneak flow” protection for the most vulnerable and critical wing leading edge panels 5 through 13; main landing gear corner void elimination; forward Reaction Control System carrier panel redesign to eliminate bonded studs; and replacing side windows 1 and 6 with thicker outer thermal panes. We accept the risk associated with not having improved Orbiter hardening capability and will reduce this risk over the long haul by continuing to pursue additional hardening measures.

Warning Devices

In addition to reducing the potential for debris generation and enhancing the Orbiter’s capability to withstand debris impact, we have greatly expanded our capability to detect debris liberation during ascent, to identify locations on the External Tank where debris may have originated, and to identify impact sites on the Orbiter Thermal Protection System for evaluation. Our ability to identify debris release during the first few minutes of ascent is enhanced through the addition of high-speed cameras, aircraft-mounted cameras, and radar. A camera installed on the External Tank will provide real-time, on-vehicle views during ascent. Video cameras on the Solid Rocket Boosters will record the condition of the External Tank inter-tank areas for later review after booster recovery. In addition to the umbilical film cameras that will be examined after the mission, images gathered from a digital camera, which will be added prior to flight in the umbilical area on the Orbiter at the External Tank interface, will be downlinked soon after achieving orbit. The Shuttle crew will also take images of the External Tank using digital cameras shortly after separation to later downlink. In the near term, we are committed to daylight launches and External Tank separation in lighted conditions on orbit to improve our ability to identify debris releases during ascent and assess the condition of the External Tank after separation and to demonstrate that our debris reduction efforts have been successful. Requirements for daylight launches and lighted External Tank separation will be reevaluated after the second mission, STS-121. To further augment impact detection capabilities, we are installing an impact detection sensor system on the interior of the wing leading edge to identify if the Reinforced Carbon-Carbon panels have been struck during ascent.

Once on orbit, the crew will use the new Orbiter Boom Sensor System to examine the condition of the wing leading edge and nose cap for signs of critical impact. The Orbiter Boom Sensor System is grappled by the Shuttle Remote Manipulator System, known as the arm, and will have a combination of a camera and a laser depth detection system to characterize the surface of the Reinforced Carbon-Carbon elements. When approaching the International Space Station, the Orbiter will be turned to present the underside to the Expedition crew, who will use digital cameras with telephoto lenses to capture images of the Orbiter’s Thermal Protection System.

Individually, each warning device/inspection method listed above will not provide the total information needed to accurately determine the condition of the Orbiter prior to committing to entry. However, together these methods provide the pieces to the puzzle, offering overlapping information to improve our knowledge of the Orbiter’s condition. We can accept failure of one or more warning devices and have the confidence that we will be able to characterize potential debris liberation and possible damage to the Thermal Protection System tile and Reinforced Carbon-Carbon components.

Special Procedures and Training

During Shuttle missions, data collected from multiple ground-based, on-vehicle, and space-based sources will be immediately evaluated through an integrated imagery evaluation process. Although we have made great strides in reducing the potential for debris generation, there remains some potential that impacts to the Orbiter Thermal Protection System will be experienced. Based on our expanded understanding of debris transport mechanisms and the capability of the Orbiter Thermal Protection System, we have established criteria for further on-orbit imagery and evaluation of potential tile damage. Where tile damage exceeds our criteria, plans are in place for further evaluation and repair, if necessary. This involves: a focused inspection using the Orbiter Boom Sensor System, a spacewalk to get close-up images and make a visual evaluation, or potentially implement a limited, experimental Thermal Protection System repair capability. In any case, the appropriate risk assessment of each course of action will be conducted and presented to the Mission Management Team for evaluation and an implementation decision. Our risk assessment process provides the Mission Management Team with our most comprehensive evaluation ever of the Orbiter’s condition prior to committing to entry.

We are mindful that our new capabilities have both built-in conservatism and limitations in completely identifying all unknowns. In many cases, the determination of debris sources and the resulting definition of potential debris environment during ascent have assumed worst-on-worst conditions. The accuracy of ascent and on-orbit imagery is dependent on the systems working as designed, weather conditions, and lighting. Potential damage to Orbiter Thermal Protection System elements has been closely scrutinized and extensively tested with the expectation that margin is available. Our limited Thermal Protection System repair techniques must be demonstrated on orbit, then analyzed and tested upon return to Earth in an effort to provide evidence of capability. We will accept the risk associated with our Thermal Protection System repair capabilities if it becomes necessary to use our limited capabilities before they are proven to return the Shuttle crew to Earth.

Although we have done everything in our capacity, we cannot completely reproduce on Earth the integrated environment experienced during a Space Shuttle mission. We acknowledge this as fact. In the unlikely event that all of our efforts to reduce risk and safely return the Space Shuttle to flight have failed, we have made plans to keep the Space Shuttle crew on the International Space Station and mount a rescue mission. Through the flight readiness review process, we will periodically evaluate the capability of the International Space Station to accommodate the Space Shuttle crew with food, water, and breathable oxygen. This capability, known as the Contingency Shuttle Crew Support, will be presented periodically to NASA Senior Management and evaluated against our ability to have a second Space Shuttle prepared for launch to rescue the crew and what the Station Program can reasonably predict as the time period the Shuttle crew could be supported on the International Space Station. For the near term, we will not launch a Space Shuttle unless the second Shuttle can be prepared and launched within the time the International Space Station can provide accommodation for the first Shuttle's crew. This capability will only be used in the most dire of circumstances and will not be used to justify flying unsafely. An evaluation of the Contingency Shuttle Crew Support and rescue mission requirements will be evaluated after the first two return to flight missions.

Additional Risk Reduction Efforts

We have made extensive improvements in other areas as well. Early on, we set up the NASA Safety and Engineering Center at Langley Research Center to provide the Agency with a cadre of highly qualified and experienced engineers to deal with tough technical issues independent from daily programmatic pressures. Through the implementation of our Agency Independent Technical Authority and the establishment of an independent Safety and Mission Assurance organizational structure, we have invigorated the critical checks and balances needed to provide for safe and reliable operations. Our Space Shuttle System Integration and Engineering Office has broader responsibilities and advanced tools that evaluate in ways never before put into practice to define the critical environment in which the Space Shuttle operates. The growth and strength of this Office has been instrumental in providing greater understanding and knowledge of the interaction of our systems as we prepare for safe and reliable Space Shuttle operations. We have further defined the roles and responsibilities of the Mission Management Team and provided critical training through courses, readings, and mission simulations to certify that team members are ready for the challenges and critical decisions they will face. We have enhanced the integrity of closeout inspections by requiring a minimum of two people at each inspection, improved our digital closeout photography system and processes, and brought our foreign object debris definition processes in line with industry practices.

We are attentive to the fact that we were criticized for focusing on schedule and not heeding the warning signs that we were overtaxing available resources in the system. Our risk management system has been enhanced and strengthened by balancing technical, schedule, and resource risks to successfully achieve safe and reliable operations. Safe and reliable operations are assured by first focusing on the technical risks and taking the needed time and resources to properly resolve technical issues. Once technical risks are eliminated or reduced to an acceptable level, Program Managers turn to the management of schedule and resource risks to preserve safety. Schedules are integral parts of Program management and provide for the integration and optimization of resource investments across a wide range of connected systems. The Space Shuttle Program must have a visible schedule with clear milestones to effectively achieve its mission. Schedules associated with all activities generate very specific milestones that must be completed for mission success. Nonetheless, schedules of milestone-driven activities will be extended when necessary to ensure safety as we have demonstrated numerous times during the return to flight process. NASA will not compromise safe and reliable operations in our effort to optimize schedules or costs.

For now, there will be a level of residual risk that will be presented to NASA Senior Management for acceptance prior to return to flight Our risk assessment/risk management process does not end with STS-114. We are committed to continuous risk evaluation of our experiences gained through each mission and will continue to factor in ongoing enhancements over time.

We have met many challenges during our journey, but we proceed with the full understanding that we have done all that is reasonably achievable and the result of our efforts offer *Discovery's* crew, led by Commander Eileen Collins, the safest Space Shuttle mission in history. We are committed to safely returning to flight and safely flying the Space Shuttle fleet until its retirement. To do less would diminish the lifelong contributions of the STS-107 crew and our astronauts who will follow their path.

Return to Flight Cost Summary

Proposed Program solutions for all return to flight (RTF) actions are reviewed by the Space Shuttle Program Requirements Control Board (PRCB) before receiving final NASA implementation approval. 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 Space Shuttle Program Manager, Deputy Manager, all Project and Element Managers, Safety and Mission Assurance personnel, and Management Integration and Planning Office. This process applies to solutions to the *Columbia* Accident Investigation Board (CAIB) recommendations as well as to the Space Shuttle Program (SSP) corrective actions.

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 is ready to recommend a comprehensive solution to a CAIB recommendation or an 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 Operations, Associate Deputy Administrator for Technical Programs, Deputy Associate Administrator for ISS [International Space Station] and SSP, Associate Administrator for Safety and Mission Assurance, Space Shuttle Program Manager, and the Office of Space Operations Center Directors (at Johnson Space Center, Kennedy Space Center, Marshall Space Flight Center, and Stennis Space Center).

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

Processes established by NASA to estimate and capture all costs related to RTF have steadily improved the accuracy of Agency budget forecasts. As the technical plan for RTF has matured, so the cost estimates have matured. NASA incurred costs in fiscal year (FY) 2003, valued at $42M, to initiate RTF actions based on preliminary CAIB recommendations. Since November 2003, additional corrective actions have been initiated, in accordance with the process described above and based on the final CAIB Report recommendations and internal SSP actions.

During FY 2004, RTF activities moved rapidly from planning to execution, with several key option "down-select" decisions being made by the end of the year. The July 2004 RTF cost estimate is considered the first credible Agency projection because it was based on a more mature technical plan. NASA estimated that RTF activities in FY 2004 would cost about $465M. By the end of the year, the actual costs totaled $496M. The costs incurred included work carried over from FY 2003 as well as late-year changes in FY 2004 technical content.

The value of RTF activities for FY 2005 is estimated at $602M, of which $413M have been approved through the PRCB. Of the remaining $189M , $73M represent the estimated value of work review by the control board, but with additional technical effort required before a directive is released, and $116M is the value of activities that are still in technical definition. As NASA gains actual flight experience, the estimates for FY 2005 and FY 2006 will be adjusted and the changes will be reported to Congress as soon as they are fully assessed.

FY 2006 is planned to be a transition year for the Shuttle Program. RTF technical content that must be sustained for the Program's remaining service life, along with the workforce required to continue safe flight, will be absorbed into the Program's baseline. Therefore, at the end of FY 2006, RTF costs will no longer be budgeted or reported separately.

Excluded from the cost estimates provided below are other RTF-related funding requirements resulting from a complete evaluation of *Columbia* accident impacts across the Program, such as replacement of hardware (e.g., cargo integration, Orbiter pressure tanks). Several solutions to improve NASA's culture and some of the Program's actions detailed in "Raising the Bar – Other Corrective Actions" are integrated into existing processes and do not always require additional funding.

Table 1. Return to Flight Budget Estimates/Implementation Plan Map for New Estimates Including Threats* **As of February 2005**

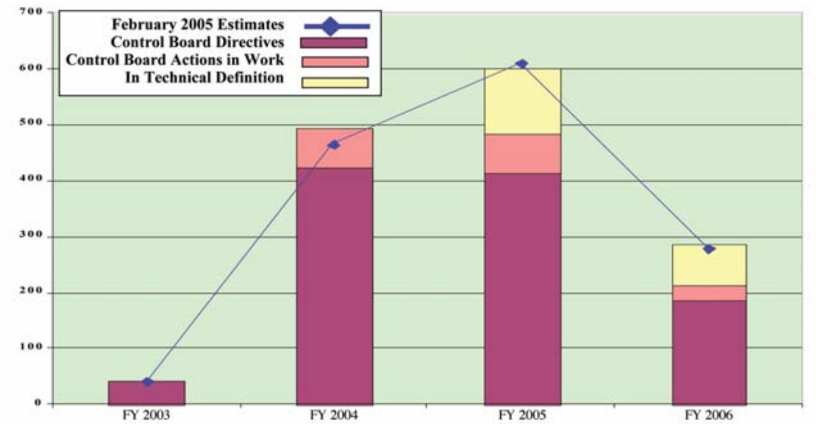
		(Cost in Millions)				Recommendation Numbers Map to Implementation Plan																													
		FY 03	FY 04	FY 05	FY 06	CAIB #3.2-1	CAIB #3.3-1	CAIB #3.3-2	CAIB #3.3-3	CAIB #3.3-4	CAIB #3.3-5	CAIB #3.4-1	CAIB #3.4-2	CAIB #3.4-3	CAIB #3.6-1	CAIB #3.6-2	CAIB #3.8-1	CAIB #3.8-2	CAIB #4.2-1	CAIB #4.2-2	CAIB #4.2-3	CAIB #4.2-4	CAIB #4.2-5	CAIB #6.2-1	CAIB #6.3-1	CAIB #6.3-2	CAIB #6.4-1	CAIB #7.5-1	CAIB #7.5-2	CAIB #7.5-3	CAIB #9.1-1	CAIB #9.2-1	CAIB #10.3-1	CAIB #10.3-2	SSP Recommendation
(1)	**Total Initiated SSP RTF Activities**	**42**	**496**	**602**	**288**																														
RE/RP	Orbiter RCC Inspections & Orbiter RCC-2 Shipsets Spares	0	39	41	5		X	X									X										X								
RE/RP	On-orbit TPS Inspection & EVA Tile Repair	20	71	167	49								X														X								X
	Orbiter Workforce	0	0	38	46																			X						X					X
RE/RP	Orbiter TPS Hardening	0	29	1	0			X																											
	Orbiter/GFE	0	8	4	0																														
RE	Orbiter Contingency	0	8	17	0																														
RE/RP	Orbiter Certification / Verification	0	47	9	0		X		X	X										X				X								X			X
RE/RP	External Tank Items (Camera, Bipod Ramp, etc.)	10	93	88	14	X								X							X														
RE/RP	SRB Items (Bolt Catcher, ETA Ring Invest., Camera)	1	14	4	0					X				X					X																X
RE/RP	Ground Camera Ascent Imagery Upgrade	8	40	13	11							X								X	X						X								
	KSC Ground Operations Workforce	0	15	38	42						X									X	X						X								X
RE/RP/AC	Other (System Intgr. JBOSC Sys, Full Cost, Additional FTEs, etc.)	4	132	178	121		X	X	X	X																		X	X	X	X				X
RE/RP	Stafford - Covey Team	0	1	4																															X
		(2)	(3)	(4)	(5)																														
	****Other RTF Related**																																		
	NASA Engineering and Safety Center (NESC)		45	77	79																								X	X	X				

RE = Reestimated Item; RP = Rephased; AC = Added Content

(1) This update includes added scope of work and improved estimates. RTF costs are stabilizing as technical solutions reach maturity. The Congress will be kept informed as we refine these requirements and associated cost estimates.
(2) NASA assumed an estimate of $94M in budget authority for FY 2003 of which $52M of FY 2003 planned work and associated cost were carried into FY 2004.
(3) The FY 2004 RTF cost estimate of $496M includes $423M of activities that have been approved for implementation. The remaining $73M of RTF activities are pending approval. As soon as these additional activities are definitized, they will be shared with Congress.
(4) The FY 2005 RTF cost estimate of $602M includes $413M of activities that have been approved for implementation. Of the remaining $189M potential, $73M is in work and $116M of activities are in technical definition. As soon as these additional activities are definitized, they will be shared with Congress.
(5) The FY 2006 RTF cost estimate of $288M includes $188M of activities that have been approved for implementation. Of the remaining $100M potential activities, $26M is in work and $74M of activities are in technical definition. As soon as these additional activities are definitized, they will be shared with Congress.

*These estimates could change due to improved estimates, additional tasks, and added scope as we better understand the implementation of RTF recommendations.
**The NASA Engineering and Safety Center (NESC) is funded through NASA's Corporate G&A. The NESC at NASA's Langley Research Center in Hampton, Va., provides comprehensive examination of all NASA programs and projects. The Center thus provides a central location to coordinate and conduct robust engineering and safety assessment across the entire Agency.

Chart 1. February 2005 RTF/CAIB Estimates



	FY 2003	FY 2004	FY 2005	FY 2006
Estimates Published in July 2004	***42***	***465***	***643***	***331***
Value of Control Board Directives Issued	**42**	**423**	**413**	**188**
Estimates for Control Board Actions Work	**0**	**73**	**73**	**26**
Estimates for Activities Still in Technical Definition	**0**	**0**	**116**	**74**
Total Board Actions/Pending Board Actions:	**42**	**496**	**602**	**288**

Table 2. February 2005 RTF Status

	FY 03	FY 04	FY 05	FY 06
TOTAL RTF	**42**	**496**	**602**	**288**
RTF Activities – Control Board Directive	**42**	**423**	**413**	**188**
RTF Activities – Been to Control Board/Awaiting	**0**	**73**	**73**	**26**
RTF Activities – In Review Process	**0**	**0**	**116**	**74**
RTF Activities – Control Board Directive	**42**	**423**	**413**	**188**
Orbiter RCC Inspections & Orbiter RCC-2 Shipsets Spares	0	39	22	0
On-Orbit TPS Inspection & EVA Tile Repair	20	71	151	20
Orbiter Workforce	0	0	33	41
Orbiter Hardening	0	29	1	0
Orbiter/GFE	0	7	4	0
Orbiter Contingency	0	8	12	0
Orbiter Certification/Verification	0	47	0	0
External Tank Items (Camera, Bipod Ramp, etc.)	10	42	25	2
SRB Items (Bolt Catcher, Camera)	1	14	4	0
Ground Camera Ascent Imagery Upgrade	8	40	13	11
KSC Ground Operations Workforce	0	15	38	42
Other (System Intgr., JBOSC Sys., SSME Tech. Assess, Ground Ops Workforce)	4	110	107	71
Stafford-Covey Team	0	1	4	
RTF Activities – Been to Control Board/Awaiting	**0**	**73**	**73**	**26**
Orbiter RCC Inspections & Orbiter RCC-2 Shipsets Spares	0	0	0	0
On-Orbit TPS Inspection & EVA Tile Repair	0	0	6	8
Orbiter Workforce	0	0	5	5
Orbiter Hardening	0	0	0	0
Orbiter/GFE	0	0	0	0
Orbiter Contingency	0	0	5	0
Orbiter Certification/Verification	0	0	0	0
External Tank Items (Camera, Bipod Ramp, etc.)	0	51	50	9
SRB Items (Bolt Catcher, Camera)	0	0	0	0
Ground Camera Ascent Imagery Upgrade	0	0	0	0
KSC Ground Operations Workforce	0	0	0	0
Other (System Intgr., JBOSC Sys., SSME Tech. Assess, Ground Ops Workforce)	0	22	7	4

Table 2. February 2005 RTF Status (Continued)

	FY 03	FY 04	FY 05	FY 06
TOTAL RTF	**42**	**496**	**602**	**288**
RTF Activities – In Review Process	**0**	**0**	**116**	**74**
Orbiter RCC Inspections & Orbiter RCC-2 Shipsets Spares	0	0	19	5
On-Orbit TPS Inspection & EVA Tile Repair	0	0	10	21
Orbiter Workforce	0	0	0	0
Orbiter Hardening	0	0	0	0
Orbiter/GFE	0	0	0	0
Orbiter Contingency	0	0	0	0
Orbiter Certification/Verification	0	0	9	0
External Tank Items (Camera, Bipod Ramp, etc.)	0	0	14	3
SRB Items (Bolt Catcher, Camera)	0	0	0	0
Ground Camera Ascent Imagery Upgrade	0	0	0	0
KSC Ground Operations Workforce	0	0	0	0
Other (System Intgr., JBOSC Sys., SSME Tech. Assess, Ground Ops Workforce)	0	0	64	46

Columbia Accident Investigation Board

Recommendation 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]

BACKGROUND

Figure 3.2-1-1 illustrates the primary areas on the External Tank (ET) being evaluated as potential debris sources for return to flight (RTF).

ET Forward Bipod Background

Before STS-107, several cases of foam loss from the left bipod ramp were documented through photographic evidence. The most significant foam loss events in the early 1990s were attributed to debonds or voids in the "two-tone foam" bond layer configuration on the intertank area forward of the bipod ramp. The intertank foam was thought to have peeled off portions of the bipod ramp when liberated. Corrective action taken after STS-50 included implementation of a two-gun spray technique in the ET bipod ramp area (figure 3.2-1-2) to eliminate the two-tone foam configuration. After the STS-112 foam loss event, the ET Project began developing redesign concepts for the bipod ramp; this activity was still under way at the time of the STS-107 accident. Dissection of bipod ramps conducted for the STS-107 investigation has indicated that defects resulting from a manual foam spray operation over an extremely complex geometry could produce foam loss.

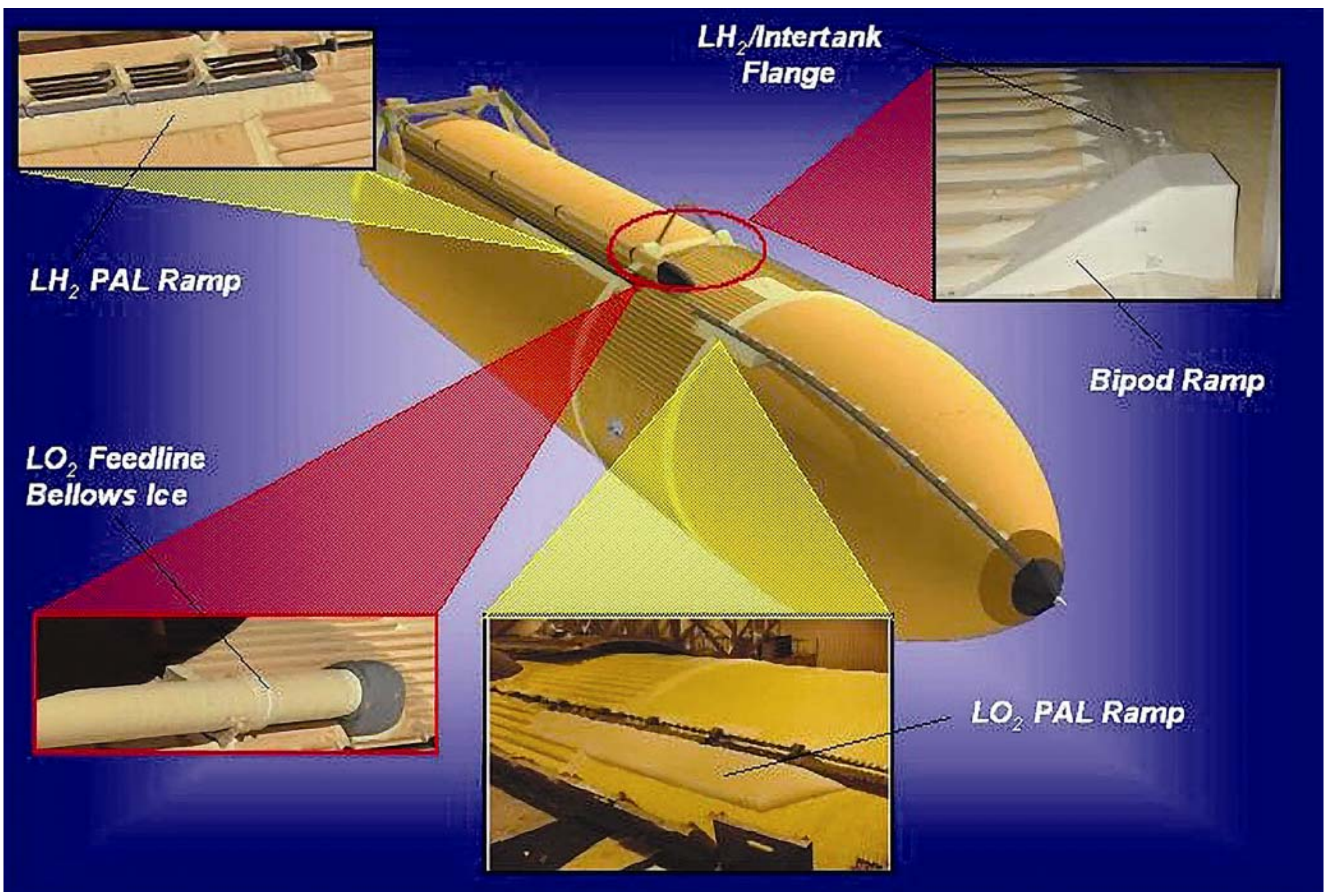


Figure 3.2-1-1. Primary potential ET debris sources being evaluated.

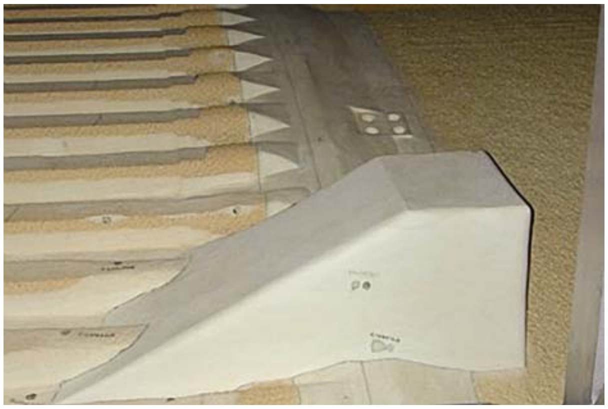


Figure 3.2-1-2. ET forward bipod ramp (foam).

Liquid Oxygen (LO_2) Feedline Bellows Background

Three ET LO_2 feedline sections incorporate bellows to allow feedline motion. The bellows shields (figure 3.2-1-3) are covered with Thermal Protection System (TPS) foam, but the ends are exposed. Ice and frost form when moisture in the air contacts the cold surface of the exposed bellows. Although Space Shuttle Program (SSP) requirements include provisions for ice on the feedline supports and adjacent lines, ice in this area presents a potential source of debris in the critical debris zone—the area from which liberated debris could impact the Orbiter.

Protuberance Airload (PAL) Ramps Background

The ET PAL ramps are designed to reduce adverse aerodynamic loading on the ET cable trays and pressurization lines (figure 3.2-1-4). PAL ramp foam loss has been observed on two prior flights, STS-4 and STS-7. The most likely cause of the losses was repairs and cryo-pumping (air-ingestion) into the Super-Light Ablator (SLA) panels under and adjacent to the PAL ramps. Configuration changes and repair criteria were revised early in the Program, thereby precluding the recurrence of these failures. However, the PAL ramps are large, thick, manually sprayed foam applications

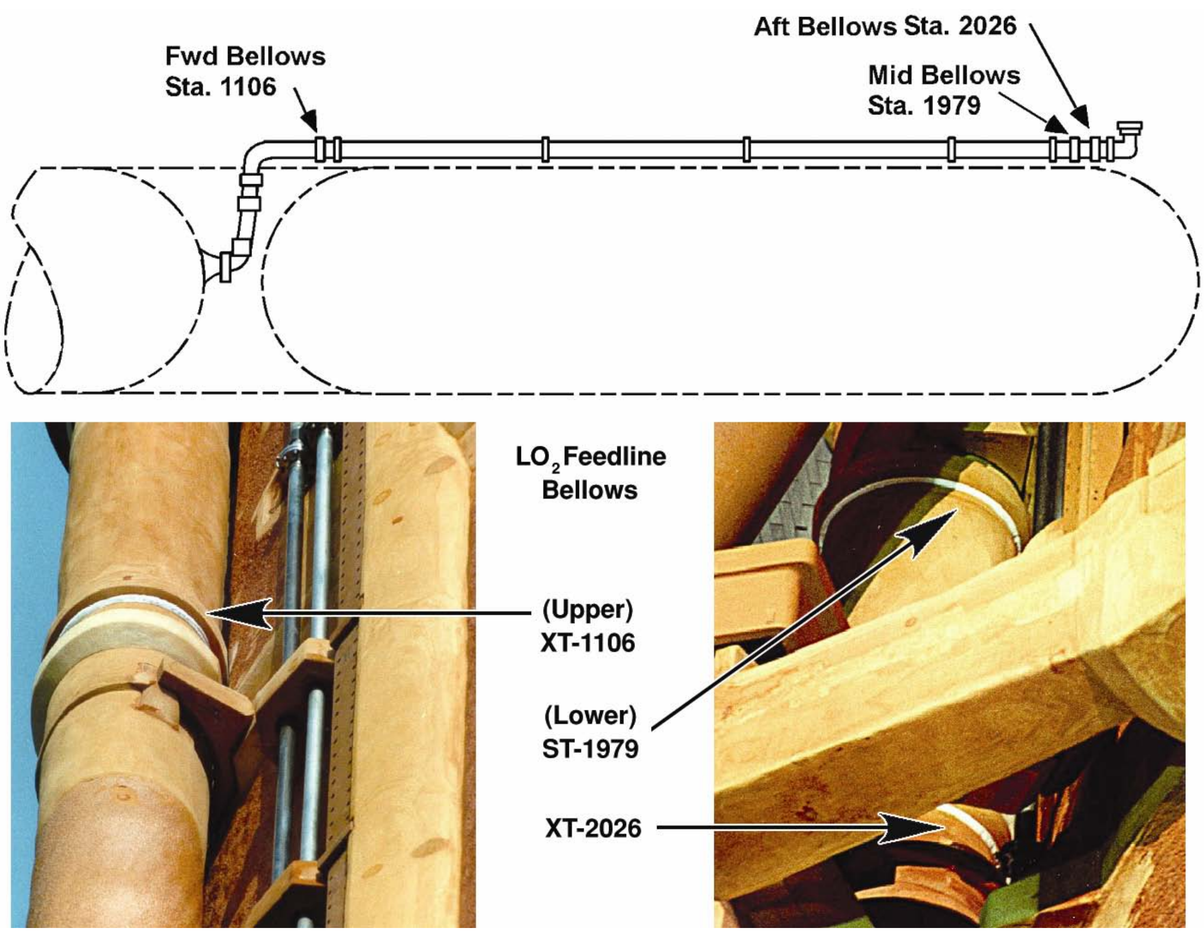


Figure 3.2-1-3. LO_2 feedline bellows.

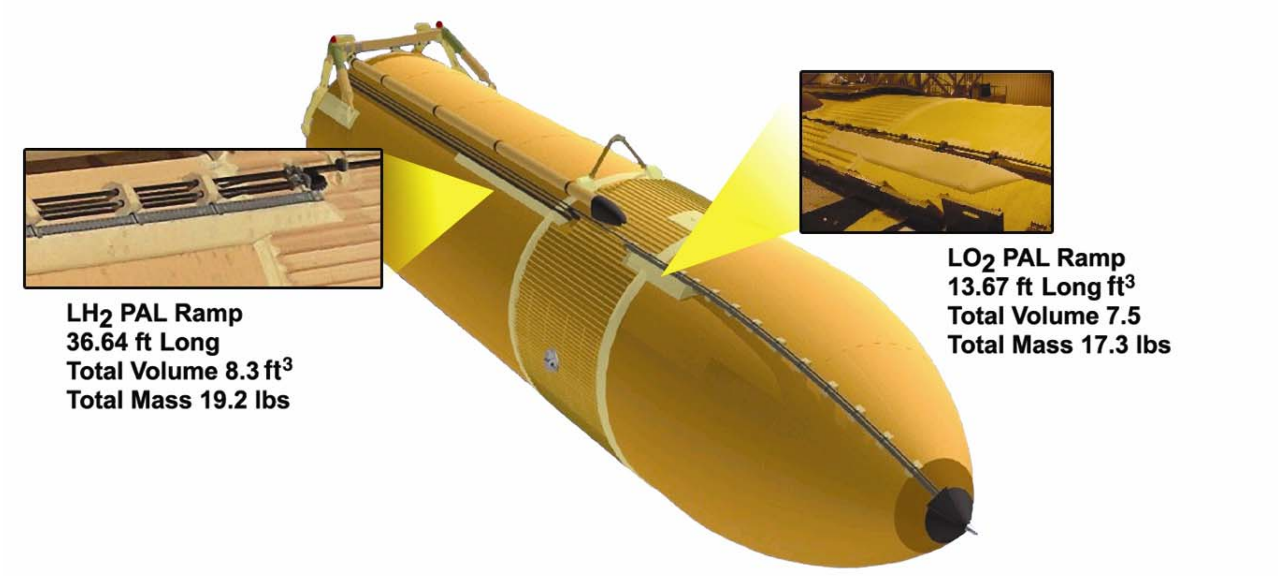


Figure 3.2-1-4. PAL ramp locations.

(using a less complex manual spray process than that used on the bipod) that could, if liberated, become the source of large debris.

ET Liquid Hydrogen (LH_2) Intertank Flange Background

The ET LH_2/intertank flange (figure 3.2-1-5) is a manually fastened mechanical joint that is closed out with a two-part manual spray foam application.

There is a history of foam loss from this area. The divots from the LH_2/intertank flange area typically weigh less than 0.1 lb. and emanate from within the critical debris zone, which is the area of the ET where debris loss could adversely impact the Orbiter or other Shuttle elements.

NASA IMPLEMENTATION

NASA has initiated a three-phase approach to eliminate the potential for debris loss from the ET. Phase 1 includes those activities that will be performed before return to flight. Phase 2 includes debris elimination enhancements that can be incorporated into the ET production line as the enhancements become available, but are not considered mandatory for RTF. Phase 3 represents potential long-term development activities that will be examined to achieve the ultimate goal of eliminating the possibility of debris loss. Implementation of Phase 3 efforts will be weighed against plans to retire the Shuttle after the completion of the International Space Station (ISS) assembly planned for the end of the decade.

As part of the Phase 1 effort, NASA is enhancing or redesigning the areas of known critical debris sources (figure 3.2-1-1). This includes redesigning the forward bipod fitting, eliminating ice from the LO_2 feedline bellows, and eliminating debris from the LH_2/intertank flange closeout. In addition to these known areas of debris, NASA is reassessing all TPS areas to verify the TPS configuration, including both automated and manual spray applications. Special consideration is being given to the LO_2 and LH_2 PAL ramps due to their size and location. This task includes assessing the existing verification data, establishing requirements for additional verification data, conducting tests to demonstrate performance against the devoting (cohesive-bond adhesion) failure mode, and evaluating methods to improve process control of the TPS application for re-sprayed hardware. NASA is also pursuing a comprehensive testing program to understand the root causes of foam shedding and develop alternative design solutions to reduce the debris loss potential. Research is being conducted at Marshall Space Flight Center, Arnold Engineering and Development Center, Eglin Air Force Base, and other sites. As part of this effort, NASA is developing nondestructive investigation (NDI) techniques to conduct ET TPS inspection without damaging the fragile insulating foam. During Phase 1, NDI will be used on the LO_2 and LH_2 PAL ramps as engineering information only; certification of the foam will be achieved primarily through verifying the application and design.

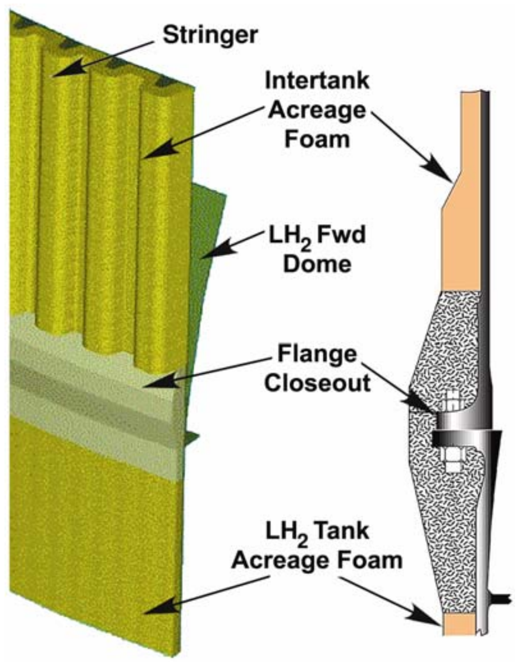


Figure 3.2-1-5. ET LH_2 flange area.

Phase 2 efforts include pursuing the redesign or elimination of the LO_2 and LH_2 PAL ramps and enhancing the NDI technology with the goal of using the technology as an acceptance tool. TPS application processes will be enhanced as appropriate to optimize the application process and incorporate more stringent process controls. Another Phase 2 effort includes the task of enhancing the TPS thermal analysis tools to better size and potentially reduce TPS on the vehicle.

The Phase 3 effort, if implemented, will examine additional means of further reducing ET debris potential. This phase would explore such concepts as rotating the LO_2 tank 180 deg to relocate all manually applied TPS closeouts outside of the critical debris zone and developing a "smooth" LO_2 tank without external cable trays or pressurization lines. Developing a smooth intertank in which an internal orthogrid eliminates the need for external stringers and implementing a protuberance tunnel in the LH_2 tank could provide a tank with a smooth outer mold line (OML) that eliminates the need for complex TPS closeouts and manual sprays.

NASA has been employing a lead tank/trail tank approach to support RTF, with the intent that the trail or second tank (intended for STS-121 or a launch-on-need rescue mission) would not ship until the final Design Certification Review (DCR). Because the final ET DCR was rescheduled after the required ship date for the trail ET, the SSP re-assessed the risk of shipping the trail ET after the DCR versus the risk of protecting the capability for a rescue mission and shipping prior to DCR. Since the ET DCR Pre-Board on Feb 23-25 disclosed no issues that would prevent shipping the trail tank, the SSP decided the least risk approach was to ship the trail ET on March 5 prior to the final ET DCR on March 8.

ET Forward Bipod Implementation Approach

NASA has initiated a redesign of the ET forward bipod fitting (figure 3.2-1-6). The baseline design change eliminates the need for large bipod foam ramps. The bipod fittings have been redesigned to incorporate redundant heaters in the base of the bipod to prevent ice formation as a debris hazard.

LO_2 Feedline Bellows Implementation Approach

NASA evaluated several concepts to eliminate ice formation on the bellows (figure 3.2-1-7). The initial trade study included a heated gaseous nitrogen (GN_2) purge, a flexible boot over the bellows, heaters at the bellows opening, and other concepts. Analysis and testing eliminated the flexible bellows boot as a potential solution since it could not eliminate ice formation within the available volume. The heated GN_2 or gaseous helium purge options were eliminated due to implementation

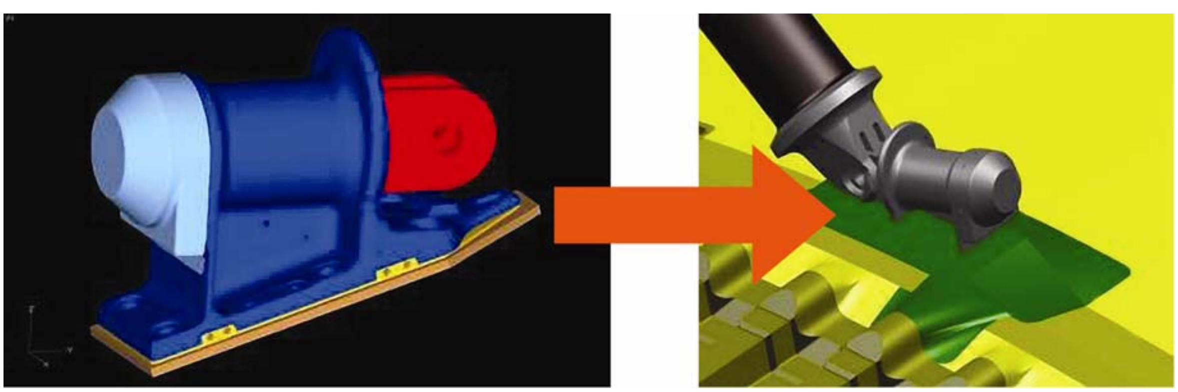


Figure 3.2-1-6. ET forward bipod redesign.

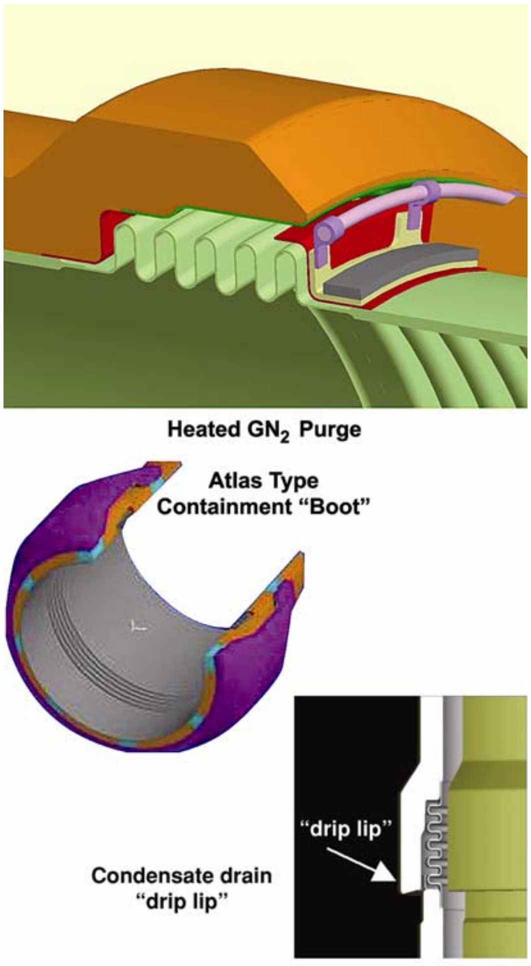


Figure 3.2-1-7. LO_2 feedline bellows design concepts.

issues and debris potential for purge hardware. It was during development testing that NASA identified the condensate drain "drip lip" as a solution that could reduce the formation of ice. Since the drip lip alone was not sufficient to completely eliminate the ice, NASA continues to pursue a solution that would complement the TPS condensate drip lip. A combination of analysis and testing will be used to verify the effectiveness of the baselined design solution.

LH_2/Intertank Flange Closeout Implementation Approach

NASA has conducted tests to determine the cause of foam liberation from the LH_2/intertank flange area. Migration of gaseous or liquid nitrogen from inside the intertank to voids in the foam was shown to be the root cause for LH_2/intertank flange foam losses during ground testing.

Several design concepts have been evaluated to ensure that the LH_2/intertank flange closeouts will not generate critical debris in flight. These concepts ranged from active purge of the intertank crevice to enhanced foam application procedures. NASA also evaluated the concept of an inner mold line (IML) barrier to preclude the migration of liquid nitrogen present in the intertank crevice to the OML foam. The selected design solution incorporates an enhanced three-step manual closeout process to eliminate voids and preclude migration of liquid nitrogen from inside the intertank region to the foam.

An update to the original Level II debris transport analyses expanded the critical debris zone that must be addressed, and significantly reduced the allowable debris mass in this region. The critical debris zone was expanded from ±67.5 deg from the top of the ET (the top of the tank directly faces the underside of the Orbiter) to greater than ±100 deg from the top of the tank. As a result, a new closeout process for the thrust panel of the intertank flange region has been developed. The plan is to apply the new closeout to the entire thrust panel, expanding the enhanced closeout region to ±112 deg from the top of the tank (figure 3.2-1-8). NASA is continuing to refine these analyses.

PAL Ramps Implementation Approach

There have been two occurrences of PAL ramp foam loss events in the history of the Shuttle, on STS-4 and STS-7. These foam losses were related to cryo-pumping of air into SLA panels and repairs at this location. Subsequent changes in configuration and repair criteria reduced the potential for foam loss from this area. However, due to the size and location of the PAL ramps, NASA placed them at the top of the priority list for TPS verification reassessment and NDI.

NASA assessed the verification data for the existing PAL ramps and determined that the existing verification is valid. To increase our confidence in the verification data, NASA dissected similar hardware and conducted performance demonstration tests. Additional design capability and confidence tests will be performed to determine the additional margin for PAL ramp performance.

Plans for the redesign or removal of the PAL ramps are continuing as part of Phase 2 of the three-phase approach to eliminate the potential for debris loss from the ET. Three redesign solutions have been down-selected (figure 3.2-1-9) and will be subjected to wind tunnel testing: eliminating the ramps; reducing the size of the ramps; and redesigning the cable tray with a trailing edge fence. A wind tunnel

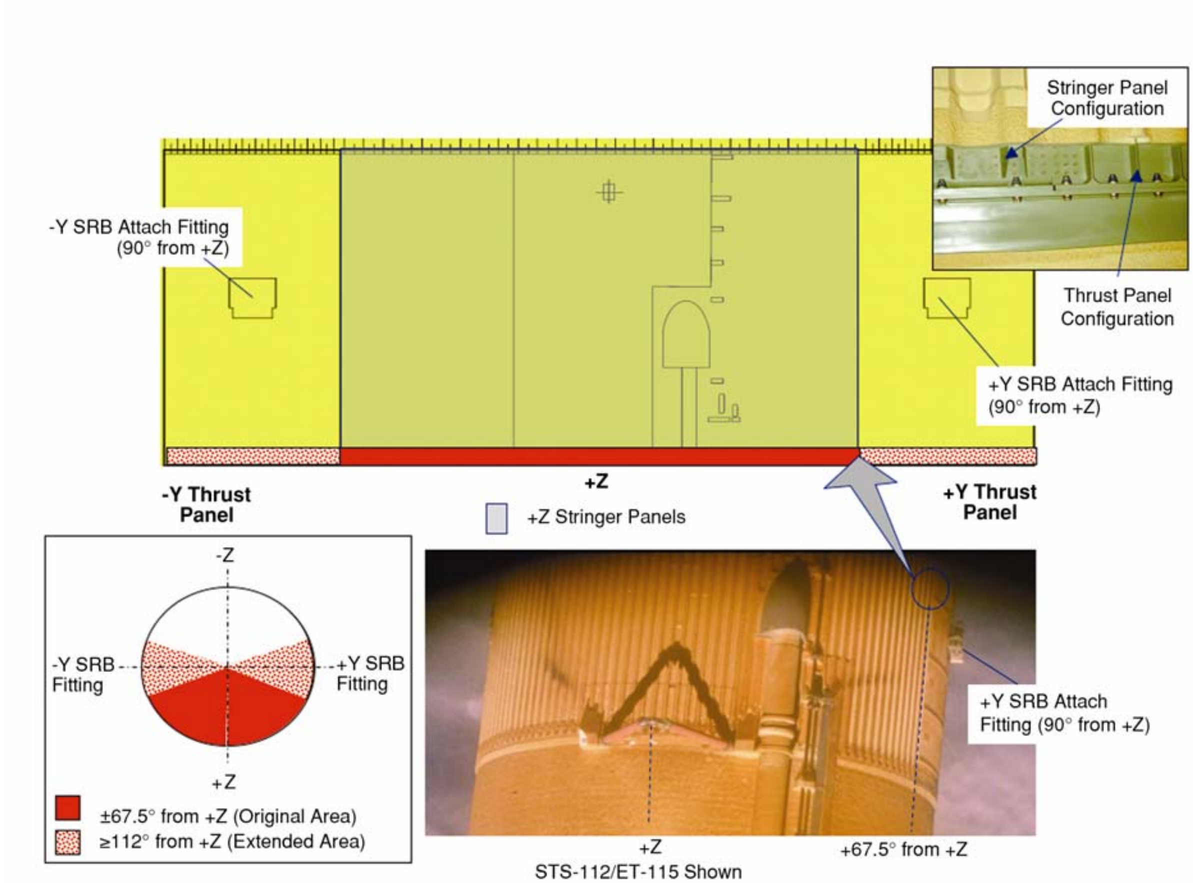


Figure 3.2-1-8. LH_2 intertank flange expanded debris zone.

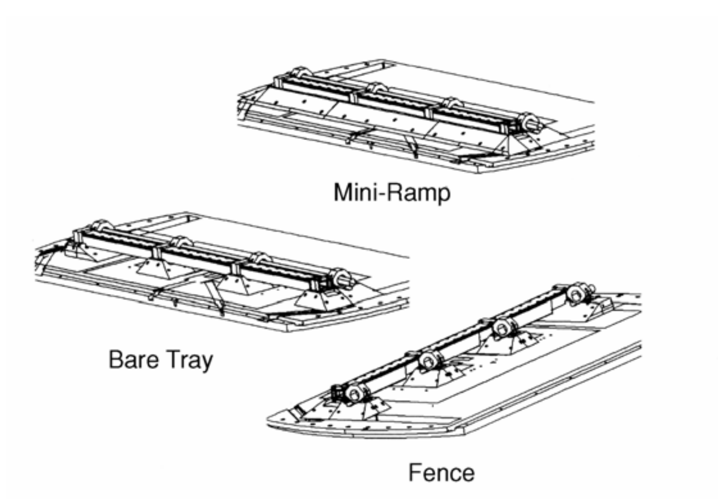


Figure 3.2-1-9. Phase 2 minimal debris ET – PAL ramp redesign solutions.

has been used to evaluate the potential for aerodynamic instabilities of the basic cable trays and associated hardware due to the proposed redesigns. The test articles are instrumented with pressure transducers, strain gauges, and accelerometers to measure the aero-elastic effect on the test articles.

TPS (Foam) Verification Reassessment Implementation Approach

NASA has developed a certification plan for both manual and automated TPS applications in the critical debris zones. This assessment will be performed using the same approach applied to the PAL ramps: evaluating existing verification data, performing additional tests and analyses to demonstrate performance against critical failure modes, and reviewing and updating of the process controls applied to re-sprayed TPS applications—those applications were determined to have a greater risk of foam loss. For re-sprayed and future TPS applications, NASA will ensure that at least two certified production operations personnel attend all final closeouts and critical hand-spraying procedures to ensure proper processing and that updates to the process controls are applied to the foam applications (ref. Recommendation 4.2-3).

NDI of Foam Implementation Approach

NASA is pursuing development of TPS NDI techniques to improve confidence in the foam application processes. If successful, advanced NDI will provide an additional level of process verification. The initial focus for RTF was on applying NDI to the PAL ramps. However for RTF, NASA will rely on the existing foam application process verification rather than on NDI to clear the tanks for flight.

During Phase 1, NASA surveyed state-of-the-art technologies, evaluated their capabilities, down-selected, and began developing a system to detect critical flaws in ET insulation systems. At an initial screening, test articles with known defects, such as voids and delaminations (figure 3.2-1-10), were provided to determine detection limits of the various NDI methods.

After the initial screening, NASA selected the Terahertz and backscatter radiation technologies and conducted more comprehensive probability of detection (POD) tests for those applicable NDI methods. The Phase 2 activities will optimize and fully certify the selected technologies for use on the ET.

STATUS

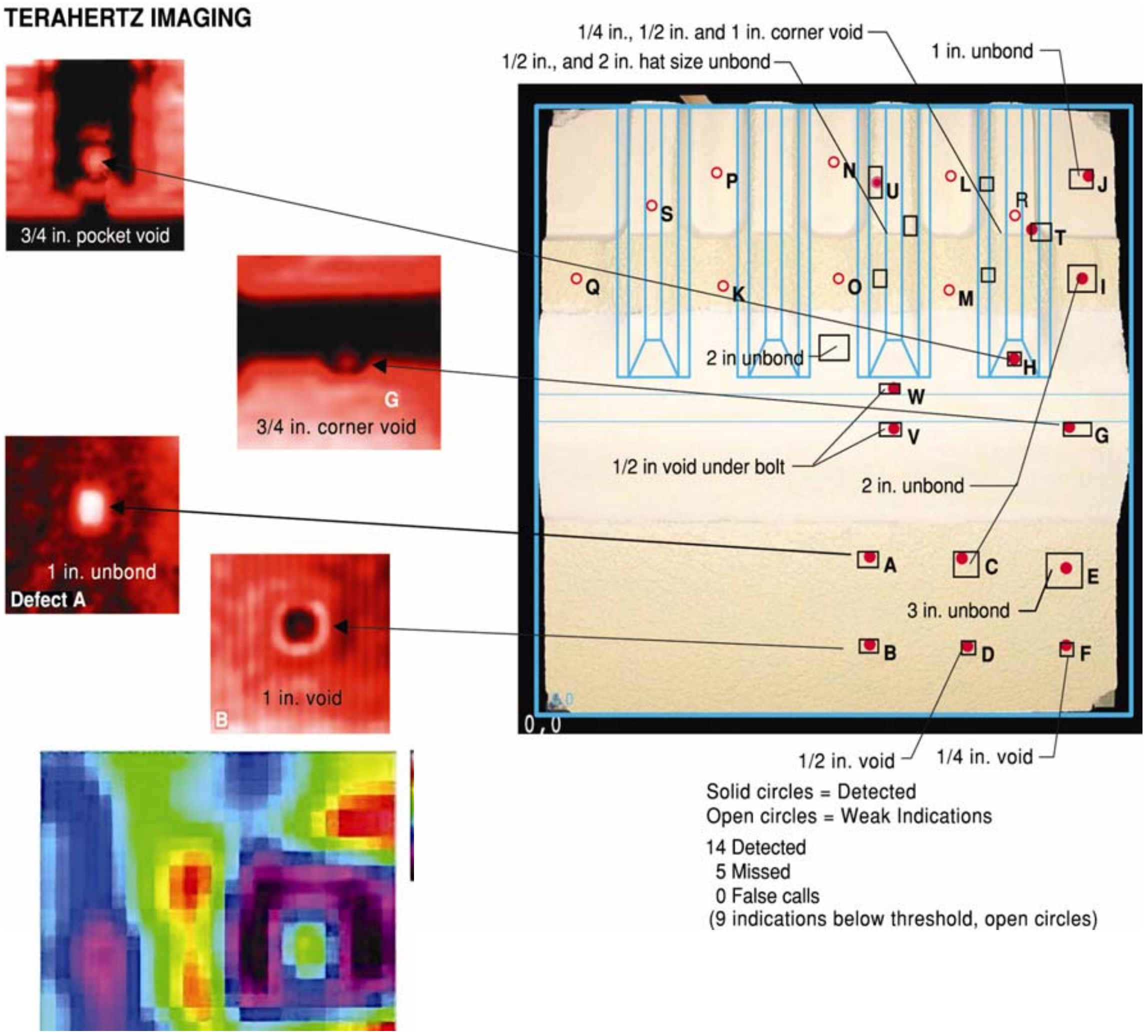
ET Forward Bipod Status

NASA has successfully completed a Systems Design Review and a Preliminary Design Review. The Critical Design Review (CDR) was held in November 2003, with a Delta CDR in June 2004. The Delta CDR Board approved the bipod redesign. A Production Readiness Review (PRR) was held in June 2004. The PRR Board gave approval for manufacturing operations to proceed with the bipod wedge foam spray on ET-120, which is now complete. The wedge spray is a foam closeout that serves as a transition area for routing of the heater harnesses from the fitting base into the intertank. The wedge is applied prior to fitting installation; after the fitting installation is complete, the final bipod closeout is performed. The final closeout application process has been verified and validated (figure 3.2-1-11).

The bipod fitting redesign verification is complete. The verification included thermal tests to determine the capability of the design to preclude prelaunch ice, with an automated heater control baselined and validated based on bipod web temperature measurements. Structural verification tests have confirmed the performance of the modified fitting in flight environments. Wind tunnel testing has verified the TPS closeout performance when exposed to ascent aerodynamic and thermal environments. The system verification included a full-scale integrated bipod test using hydrogen, the tank fluid, a prototype ground control system to demonstrate system performance, and thermal-vacuum test with combined prelaunch and flight environments to demonstrate TPS performance.

LO_2 Feedline Bellows Status

NASA selected the TPS “drip lip” option to address ice formation on the LO_2 feedline bellows. The drip lip diverts condensate from the bellows and significantly reduces ice formation. Since the drip lip alone is not sufficient to completely eliminate the ice, NASA will conduct ice tests to characterize the amount and type of residual ice formed during prelaunch with the TPS drip lip only. For the short term, launch commit criteria (LCC) will be established to specify the allowed residual ice prelaunch. Ice formation estimates, transport analysis, and the LCC will form the basis from which NASA can and will accept the risk associated with flying in the short term without further modifications. For the long term, a solution to complement the TPS condensate drip lip will be implemented. Ice mitigation techniques at the launch pad are being evaluated and include an infrared projector, warm gas purging via extendable arm, the turbofan exhaust directed between the flight elements. On-vehicle heaters at the forward bellows cavity opening are also under development. Through debris transport analysis, NASA has determined that, if liberated, the ice at the two aft bellows locations (station 1979 and station 2026) would not impact the Orbiter RCC; therefore, no additional action is required for those locations (figure 3.2-1-12).



1-in. Spray-on Foam Insulation (SOFI) to Al delamination imaged with Backscatter Radiography

Figure 3.2-1-10. Terahertz images.

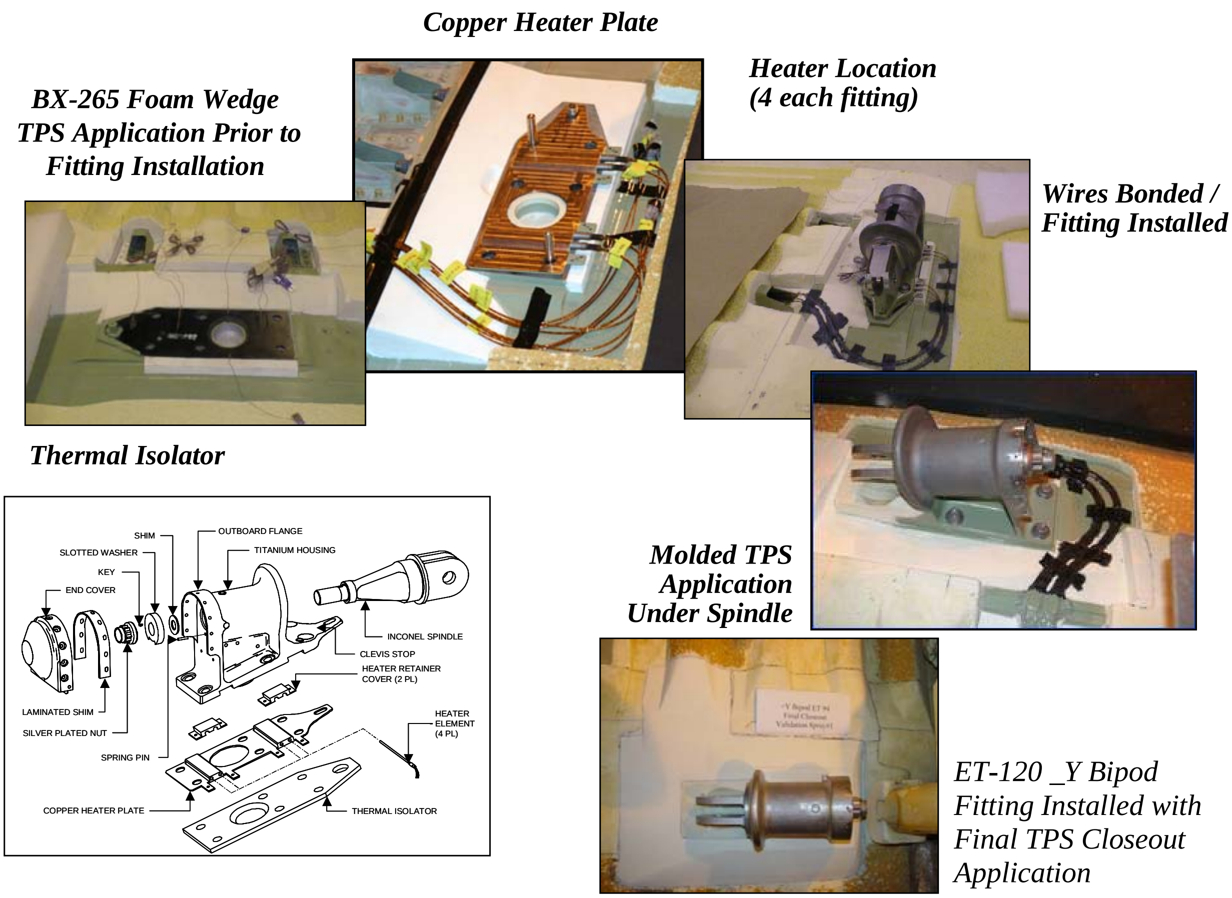


Figure 3.2-1-11. Bipod fitting redesign and TPS closeout.

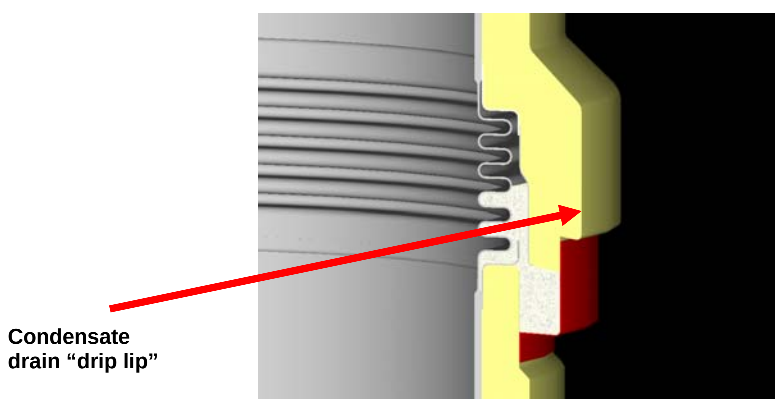


Figure 3.2-1-12. LO_2 feedline bellows condensate "drip lip."

Remaining open work for verification of the drip lip design includes cryoflex capability verification of the TPS drip to the bellows rain shield.

LH_2/Intertank Flange Closeout Status

NASA has successfully determined the root cause of foam loss. Liquid nitrogen was formed when the gaseous nitrogen used as a safety purge in the intertank came into contact with the extremely cold hydrogen tank dome and condensed into liquid. The liquid nitrogen migrated through intertank joints, fasteners, vent paths, and other penetrations into the foam and then filled voids in the foam caused by unacceptable variability in the manual foam application. During ascent, the liquid nitrogen returned to a gaseous state, pressurizing the voids and causing the foam to detach.

NASA evaluated the foam loss in this region through rigorous testing and analysis. First, a series of 1 ft $\times$1 ft aluminum substrate panels with induced voids of varying diameters and depths below the foam surface was subjected to the vacuum, heat profiles, and backface cryogenic temperatures experienced during launch. These tests were successful at producing divots in a predictable manner.

Follow-on testing was conducted on panels that simulated the LH_2 intertank flange geometry and TPS closeout configuration to replicate divot formation in a flight-like configuration. Two panel configurations were simulated: (1) a three-stringer configuration and (2) a five-stringer configuration. The panels were subjected to flight-like conditions, including front face heating, backface cryogenics (consisting of a 1.5-hour chill-down, a five-hour hold, and an eight-minute heating), ascent pressure profile, and flange deflection. These tests were successful at demonstrating the root cause failure mode for foam loss from the LH_2 tank/intertank flange region.

With this knowledge, NASA evaluated the LH_2/intertank closeout design to minimize foam voids and nitrogen leakage from the intertank into the foam (figure 3.2-1-5). Several design concepts were initially considered to eliminate debris, including incorporating an active helium purge of the intertank crevice to eliminate the formation of liquid nitrogen and developing enhanced foam application procedures.

Testing indicated that a helium purge would not completely eliminate the formation of foam divots since helium, too, could produce enough pressure in the foam voids to cause divot formation. As a result, the purge solution was eliminated from consideration.

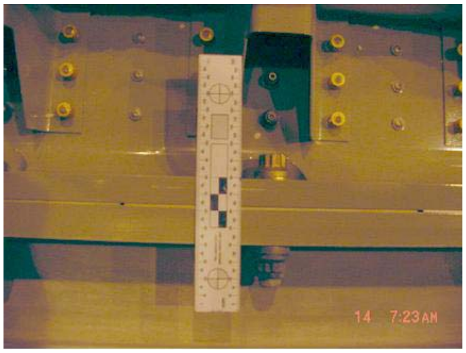
NASA also pursued a concept of applying a volume fill or barrier material in the intertank crevice to reduce or eliminate nitrogen condensation migration into the voids. However, analyses and development tests showed that the internal flange seal and volume fill solution may not be totally effective on tanks that had existing foam applications. As a result, this concept was also eliminated from consideration.

The existing intertank closeout is being removed and replaced with the three-step enhanced closeout. NASA is focusing on the enhanced TPS closeout in the LH_2 intertank area to reduce the presence of defects within the foam by using this three-step closeout procedure. This approach greatly reduces or eliminates void formations in the area of the flange joining the LH_2 tank to the intertank. The flange bolts in this area are reversed to put the lower bolt head profile at the lower flange. The LH_2 tank side of flange (shown in figure 3.2-1-13) will provide the foam application technician a much less complex configuration for the foam spray application and subsequently reduce the potential for void formation behind the bolt head. The higher profile (nut end) will be encapsulated in the stringer or rib pocket closeout prior to final closeout application. The application process for the intertank stringer panels is shown in figure 3.2-1-14. The stringer panels are the intertank panels ±67.5 deg from the centerline of the tank directly below the Orbiter.

The areas beyond ±67.5 deg that remain in the critical debris zone are the intertank thrust panels. The geometry of these panels is simplified by hand-spraying the thrust panel pockets prior to applying the final closeout shown in Steps 2 and 3 of figure 3.2-1-14.

In addition, a study has been performed at both KSC and the Michoud Assembly Facility (MAF) to reduce the potential for TPS damage during ground processing. The study identified a series of recommendations, including reducing access to critical areas of the ET, installing debris safety barriers, improving the work platforms in the area, and investigating a topcoat that would more readily show handling damage. Testing performed on eight panels using the enhanced closeout configuration demonstrated the effectiveness of the closeout; there were no foam cracks or divots formed in any of the tests.

NASA now understands the failure mechanism of the foam and will implement the appropriate solutions. The baseline flange closeout enhancement (±112 deg from the +Z, excluding area under LO_2 feedline and cable tray) uses a multipronged approach. The baseline includes the external three-step closeout, point fill of the structure, reversal of the flange bolts, and sealant on the threads of the bolts. The external three-step enhanced procedure



Previous orientation – bolt head forward (top)

New orientation – bolt head aft (bottom)

Figure 3.2-1-13. Flange bolt reversal.

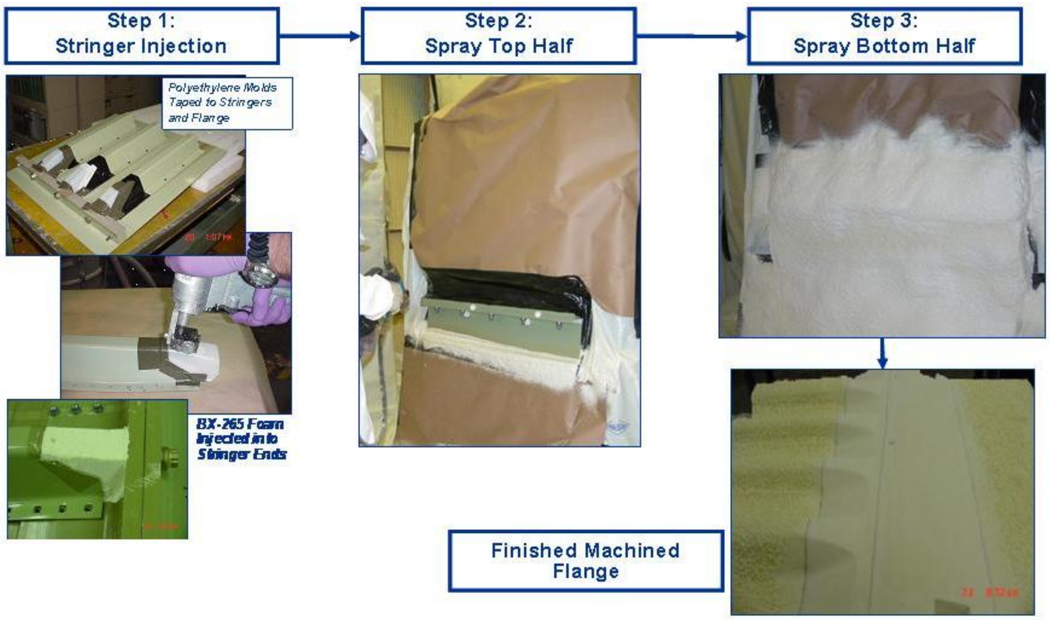


Figure 3.2-1-14. Three-step closeout for LH_2 tank/intertank.

reduces foam loss to a level within acceptable limits by removing critical voids in the foam. The newly enhanced ET-120 closeout was applied using a verified and validated TPS application process. During production of the ET-120 flange closeout (and all subsequent flange closeouts), a series of high-fidelity production test articles was used to demonstrate the application on the flight hardware. The acceptability of the closeout is demonstrated through a series of mechanical property tests and dissection of the foam to determine process performance. Defect tolerance of the flange closeout design will be demonstrated in a combined environment test (end of March 2005).

PAL Ramp Status

Because the PAL ramps have an excellent flight history and have not lost foam since the last configuration change after STS-7, NASA's baseline approach for RTF is to develop sufficient certification data to accept the minimal debris risk of the existing design. Evaluating the available verification data and augmenting them with additional tests, analyses, and/or inspections will accomplish this. This will include dissecting several existing PAL ramps to understand the void sizes produced by the existing PAL ramp TPS process.

NASA has obtained sufficient data to proceed to launch with the existing LO_2 and LH_2 PAL ramps. The LH_2 PAL ramp is approximately 38 ft in length. A portion of the LH_2 PAL ramp spans the high-risk LH_2 flange closeout. The forward 10 ft of the LH_2 PAL ramp have been removed to access the underlying intertank/LH_2 tank flange closeout. By removing the10-ft section, an enhanced LH_2/intertank flange closeout can be performed. The removed portion of the LH_2 PAL ramp will be replaced with an improved process manual spray application.

As a part of the Phase 2 activities, NASA developed concept designs to eliminate the large PAL ramps. Redesign options included eliminating the PAL ramps altogether, implementing smaller mini-ramps, or incorporating a cable tray aero block fence on either the leading or trailing edge of the tray. NASA performed analysis of the aerodynamic loading on the adjacent cable trays and conducted subscale and full-scale wind tunnel testing of the cable trays to determine the aerodynamic and aero-elastic characteristics of the trays. The tests provided sufficient confidence in the analysis to continue pursuit of ramp elimination. Additionally, NASA has approved the use of flight instrumentation to obtain data to validate the flight environments used in the test and analysis. The instrumentation package, containing accelerometers, is planned to fly on the second ET planned for RTF mission STS-121. These data, in addition to the tests and analysis, will provide the basis for determining the aerodynamic stability of the cable trays with the design modifications.

TPS (Foam) Verification Reassessment Status

The SSP has established a TPS Certification Plan for the ET RTF efforts. This plan will be applied to each TPS application within the critical debris zone. Evaluating the available verification data and augmenting them with additional tests, analyses, and/or inspections will accomplish this plan. It also includes dissection of TPS applications within the critical debris zone to understand the void sizes produced by the existing TPS processes.

The TPS applications will undergo visual inspection, verification of the TPS application to specific acceptance criteria, and validation of the acceptance criteria. A series of materials properties tests is being performed to provide data for analysis. Acceptance testing, including raw and cured materials at both the supplier and the MAF, is being used to demonstrate the as-built hardware integrity is consistent with design requirements and test databases. Mechanical property tests, including plug pull, coring, and density, are being performed on the as-built hardware.

NASA is also conducting stress analysis of foam performance under flight-like structural loads and environmental conditions, with component strength and fracture tests grounding the assessments. Dissection of equivalent or flight hardware is under way to determine process performance. TPS defect testing is being conducted to determine the critical defect sizes for each application. In addition, various bond adhesion, cryoflex, storage life verification, cryo/load/thermal tests, and acceptance tests are under way to fully certify the TPS application against all failure modes. Finally, a Manual Spray Enhancement Team has been established to provide recommendations for improving the TPS closeout of manual spray applications. Production-like demonstrations are being performed upon completion of all design and development efforts to verify and validate the acceptability of the production parameters of redesigned or re-sprayed TPS applications.

NDI of Foam Status

Activities have been initiated to develop NDI techniques for use on ET TPS. The following prototype systems under development by industry and academia were evaluated:

- Backscatter Radiography: University of Florida
- Microwave/Radar: Marshall Space Flight Center, Pacific Northwest National Labs, University of Missouri, Ohio State
- Shearography: KSC, Laser Technology, Inc.
- Terahertz Imaging: Langley Research Center, Picometrix, Inc., Rensselaer
- Laser Doppler Vibrometry: Marshall Space Flight Center, Honeywell

The Terahertz Imaging and Backscatter Radiography systems were selected for further POD testing based on the results of the initial proof-of-concept tests. The microwave system will still be evaluated during the Phase 2 development activity. This additional POD testing has been completed, but the results are still being analyzed. The preliminary results, however, indicate that these technologies are not yet reliable enough to be used to certify TPS applications over complex geometries, such as the bipod or intertank flange regions. The technologies will continue to be developed to support PAL ramp evaluation and for Phase 2 implementation.

FORWARD WORK

- Finalize critical characteristics that could cause catastrophic damage to the Orbiter.

- Complete the redesigned hardware verification testing.
- Complete the TPS certification activities, including generating the materials properties, obtaining the dissection results, determining the critical debris size for each application, and completing the required assessments.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Jun 04 (Completed)	Complete bipod redesign Delta CDR Board
SSP	Apr 04 (Completed)	Perform NDI of PAL ramp on ET-120 (1^{st} RTF tank)
SSP	Jul 04 (Completed)	Complete validation of LH_2/intertank stringer panel closeout
SSP	Aug 04 (Completed)	Complete validation of LH_2/intertank thrust panel closeout
SSP	Aug 04 (Completed)	Complete bipod TPS closeout validation
SSP	Nov 04 (Completed)	Complete bellows “drip lip” validation
SSP	Nov 04 (Completed)	Complete bipod retrofit on ET-120
SSP	Nov 04 (Completed)	Complete flange closeout on ET-120
SSP	Dec 04 (Completed)	Critical debris characterization Initial phase testing
SSP	Dec 04 (Completed)	Phase I ET DCR
SSP	Dec 04 (Completed)	Ready to ship ET-120 to KSC
SSP	Mar 05 (Completed)	Phase II ET DCR
SSP	Mar 05	Critical debris characterization final phase testing
SSP	Mar 05	Final External Tank Certification (DCR Board)

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

NASA agrees that the STS-107 accident clearly demonstrated that the Space Shuttle's Thermal Protection System (TPS) design, including the Reinforced Carbon-Carbon (RCC) panels and acreage tiles, was too vulnerable to impact damage from the existing debris environment. As a result, NASA has initiated a broad array of projects to define critical debris (explained in NASA's response to the *Columbia* Accident Investigation Board (CAIB) Return to Flight (RTF) Recommendations 3.3-1 and 6.4-1), to work aggressively to eliminate debris generation (CAIB Recommendation 3.2-1), and to harden the Orbiter against impacts.

NASA has chosen to address the CAIB requirement by (1) initiating a program of Orbiter hardening and (2) determining the impact resistance of current materials and the effect of likely debris strikes. NASA's Orbiter hardening program is mature and well defined. Four modifications to the Orbiter have been or are being implemented for the STS-114 RTF mission. Impact tolerance testing is also a well-defined, ongoing effort that has identified preliminary impact tolerance data for use by all elements of the Space Shuttle Program (SSP).

NASA IMPLEMENTATION

Orbiter Hardening

NASA's fundamental RTF rationale assumes that a needed reduction in risk to ascent debris damage will be accomplished primarily through modifications to the External Tank (ET). The definition of critical debris is derived from the ability of the current Orbiter, not the hardened Obiter, to withstand impact damage. Therefore, Orbiter hardening provides an additional level of risk mitigation above and beyond NASA's primary control. Orbiter hardening will be implemented as feasible, an approach consistent with the CAIB recommendation to *initiate* a program of Orbiter hardening prior to RTF.

NASA formed an Orbiter Hardening Team to identify options for near-term TPS improvements in critical locations. Initially, the SSP categorized Orbiter hardening into eight candidate design families with 17 design options for further assessment. Each TPS enhancement study was evaluated against the damage history, vulnerability, and criticality potential of the area and the potential safety, operations, and performance benefits of the enhancement. The team focused on those changes that achieve the following goals: increase impact durability for ascent and micrometeoroid orbital debris impacts; increase temperature capability limits; reduce potential leak paths; selectively increase entry redundancy; increase contingency trajectory limits; and reduce contingency operations such as on-orbit TPS repair. These candidates were presented to the SSP Program Requirements Control Board (PRCB), which prioritized them. The result was a refined set of 16 Orbiter hardening options in eight different design families.

The Orbiter hardening options are being implemented in three phases. Four projects were identified as Phase I and will be implemented before STS-114, based on maturity of design and schedule for implementation. These include: front spar "sneak flow" protection for the most vulnerable and critical RCC panels 5 through 13; main landing gear corner void elimination; forward Reaction Control System carrier panel redesign to eliminate bonded studs; and replacing side windows 1 and 6 with thicker outer thermal panes. All four modifications are being implemented on all of the Orbiters. These changes increase the impact resistance of the Orbiter in highly critical areas such as the wing spar, main landing gear door (MLGD), and windows, to reduce existing design vulnerabilities.

There are two Phase II options: "sneak flow" front spar protection for the remaining RCC panels 1 through 4 and 14 through 22, and MLGD enhanced thermal barrier redesign. Both of these projects are in the final design phase. Implementation of the Phase II modifications may begin as early as one year after RTF and will be executed during Orbiter Major Modification periods or during extended between-mission flows.

Family	Redesign Proposal	Phase
WLESS	"Sneak Flow" Front Spar Protection (RCC #5 – 13)	I
	"Sneak Flow" Front Spar Protection (RCC # 1 – 4, 4 – 22)	II
	Lower Access Panel Redesign/BRI 20 Tile Implementation	III
	Insulator Redesign	III
	Robust RCC	III
Landing Gear and ET Door Thermal Barriers	Main Landing Gear Door Corner Void	I
	Main Landing Gear Door Enhanced Thermal Barrier Redesign	II
	Nose Landing Gear Door Thermal Barrier Material Change	III
	External Tank Door Thermal Barrier Redesign	III
Vehicle Carrier Panels – Bonded Stud Elimination	Forward RCS Carrier Panel Redesign – Bonded Stud Elimination	I
Tougher Lower Surface Tiles	Tougher Periphery (BRI 20) Tiles around MLGD, NLGD, ETD, Window Frames, Elevon Leading Edge and Wing Trailing Edge	III
	Tougher Acreage (BRI 8) Tiles and Ballistics SIP on Lower Surface	III
Instrumentation	TPS Instrumentation	III
Elevon Cove	Elevon Leading Edge Carrier Panel Redesign	III
Tougher Upper Surface Tiles	Tougher Upper Surface Tiles	III
Vertical Tail	Vertical Tail AFSI High Emittance Coating	III

Table 3.3-2-1. Eight Design Families Targeted for Enhancement.

Finally, the remaining Phase III options are those that are less mature but hold promise for increasing the impact resistance of the Orbiter. These options will be implemented as feasible, as designs mature, and as implementation opportunities become available. For instance, NASA is actively developing new toughened tiles for the Orbiter TPS. These tiles will be installed as soon as possible around more critical areas such as the landing gear doors. In less critical areas, they will be installed as existing tiles require replacement. Two of the Phase III options have been approved by the SSP for further development: toughened lower and upper surface tiles and stronger wing leading edge RCC.

Impact Tolerance

NASA's Orbiter Debris Impact Assessment Team (ODIAT) is making significant progress in determining the actual impact tolerance of TPS tile and RCC by testing the TPS ability to withstand ET foam, ice, and ablator impacts. Preliminary impact tolerance data are being used by SSP project offices to modify hardware as necessary to assure no critical debris is released.

Tile

The majority of tests to determine TPS tile impact tolerance—using foam, ice, and ablator projectiles—are complete. The remaining testing will be completed by March 2005. Remaining impact testing includes both foam and ice tests on advanced felt reusable surface insulation (AFRSI) blankets and on "special configuration" tiles (such as those around doors and windows) and a small number of tests of the newly redesigned Reaction Control System (RCS) jet rain covers against AFRSI. High-density ice impact tests on acreage tiles and ablator impact tests were completed in September 2004.

RCC

Impact and damage tolerance testing is being performed at several NASA field centers and other test facilities, using both RCC coupons and full-scale RCC panels. This testing is planned for completion in March 2005. Structural and thermal testing of damaged RCC samples is revealing exactly how much damage can be allowed (damage tolerance) while still ensuring a safe return for the crew and vehicle. Testing should be completed by early April 2005.

Analysis and modeling work is continuing for both the RCC and the tile. Since it is impossible to test every potential damage configuration, analytical models are being developed to predict the capability of damaged tile and RCC. Actual testing provides the real data to "anchor" these models, so they can accurately predict test results. The test data collected are used to develop and verify two types of RCC and tile models. One model type will be used in real-time situations where a "quick look" is needed. This model type provides a conservative answer to possible damage assessments. The second type of model will provide accurate predictions of the onset of detectable damage. This model may take several days to code and run, and will be used prelaunch for risk assessment and in flight for situations where time is available and detailed results are necessary. The detailed tile and RCC models have shown very good correlation to actual testing with foam and ice projectiles, and developmental work on the other models is continuing.

STATUS

Orbiter Hardening

NASA identified four Orbiter hardening options that must be completed before RTF and has begun or has completed implementation of them on all three Orbiters. Beyond RTF, NASA will continue to pursue Phase II and III hardening options and will implement those that are feasible at the earliest possible opportunity.

Impact Tolerance

The test-verified models have established impact tolerance thresholds for both foam and ice against both tile and RCC. These impact tolerance thresholds are the levels at which detectable damage begins to occur and vary, depending on RCC panel location of the acreage tile location. The thresholds have been provided to the Program for risk assessment of the TPS capability against the expected debris environment.

Damage Tolerance

Damage tolerance is defined as the level of damage from a debris strike that can be tolerated while still safely completing the mission. For tile, preliminary damage tolerance thresholds have been established through testing and test-verified models and are being assessed for risk compared with the expected debris environment. Testing thus far has shown tile to be tolerant to moderate levels of impact damage, except in certain areas of reduced thickness or adjacent to the MLGDs. Test-verified models have also established both impact tolerance and damage tolerance thresholds for the RCC. Testing also shows that RCC cannot tolerate any significant loss of coating from the front surface in areas that experience full heating/temperatures. This is of concern because impacts can create subsurface delamination of the RCC. Testing indicates that loss of front-side coating in areas that are hot enough to oxidize and/or promote full heating of the damaged substrate can cause unacceptable erosion damage into the delaminated areas, creating an even larger erosion area. Further testing and modeling has shown that, although the hottest areas on the wing leading edge (bottom and apex surfaces) cannot tolerate any significant coating loss, other cooler areas (top surface of the wing leading edge) can tolerate some amount of coating loss and subsurface delamination. Testing and model development work continues to fully map the damage tolerance capabilities of the wing leading edge RCC depending on panel and location (top surface, apex or bottom surface).

FORWARD WORK

Orbiter Hardening

The SSP has reviewed and approved the corrective measures taken in response to this Recommendation. The SSP Manager has reviewed the suite of activities summarized above and concluded that, taken as an integrated plan, it fully satisfies the CAIB RTF recommendation to initiate a program to increase the Orbiter's ability to sustain minor debris damage. As NASA's analysis becomes more defined, we will continue to enhance the steps taken to improve the Orbiter's resistance to potential impact damage beyond RTF.

Impact Tolerance Testing

In March 2005, NASA will complete the tests to provide insight into the material and physical properties of the TPS. NASA will also validate the analytical models and tools used preflight to establish impact and damage tolerance thresholds, as well as to assess any damage seen on orbit. NASA will review our response to this CAIB recommendation with the Stafford-Covey Return to Flight Task Group.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Jun 03 (Completed)	Initial plan reported to PRCB
SSP	Aug 03 (Completed)	Initial Test Readiness Review held for Impact Tests
ODIAT	Oct 03 (Completed)	Initial Panel 9 Testing
SSP	Nov 03 (Completed)	Phase I Implementation Plans to PRCB (MLGD corner void, FRCS carrier panel redesign—bonded stud elimination, and WLE impact detection instrumentation)
SSP	Jan 04 (Completed)	Phase II Implementation Plans to PRCB (WLE front spar protection and horse collar redesign, MLGD redundant thermal barrier redesign)
ODIAT	Aug 04 (Completed)	Panel 16R Testing
SSP	Sep 04 (Completed)	Finalize designs for modified wing spar protection between RCC panels 1–4 and 14–22 on OV-103 and OV-104
SSP	Oct 04 (Completed)	Conclude feasibility study of the Robust RCC option
SSP	Jan 05 (Completed)	Complete analysis and preliminary design phase for robust RCC
SSP	Feb 05 (Completed)	Complete modification of wing spar protection behind RCC panels 5–13 on OV-103
ODIAT	Mar 05	Tile Impact Testing Complete
ODIAT	Mar 05	RCC Impact Testing Complete
ODIAT	Mar 05	Final Tile and RCC Model Verification (Program Baselining of models and tools)
SSP	Apr 05	Damage Tolerance Test and Analysis Complete (SSP baseline of models and tools)
ODIAT	Apr 05	RCC Materials Testing Complete

Columbia Accident Investigation Board

Recommendation 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 undocking. [RTF]

BACKGROUND

The fundamental rationale for return to flight (RTF) is to modify the External Tank (ET) to control critical debris liberation. NASA will resume Shuttle missions only when we have confidence that the ET will not liberate critical debris. While Thermal Protection System (TPS) inspection and repair capability is an important part of the on-orbit TPS risk mitigation plan, it does not offer an alternative to prelaunch flight rationale requiring the ET to perform at the level determined necessary to control critical debris liberation. Nevertheless, NASA agrees that inspection capability, as well as the development of tools and process to support potential on-orbit TPS repair, is important.

There are additional risks associated with creating and deploying a fully autonomous inspection capability without International Space Station (ISS) resources. While all space flight is inherently risky, there are both on-orbit and ground processing requirements that would be unique to an autonomous mission. While similar issues—such as TPS inspection and repair, Contingency Shuttle Crew Support (CSCS) and potentially rescue—exist for missions to the ISS, they can be mitigated more easily, in part due to the increased time available for understanding and responding to an emergency situation at the ISS. For an autonomous mission, the options and available time for dealing with an on-orbit emergency are greatly reduced, posing additional risk to the mission. Therefore, NASA has decided to focus its development of TPS inspection and repair on those capabilities that enhance the Shuttle's suite of assessment and repair tools, while taking full advantage of ISS resources.

The Space Flight Leadership Council has directed the Space Shuttle Program (SSP) to focus its efforts on developing and implementing inspection and repair capability appropriate for the first return to flight missions using ISS resources as required. NASA will focus its efforts on mitigating the risk of multiple failures (such as an ISS mission failing to achieve the correct orbit or dock successfully, or the Orbiter being damaged during or after undocking and suffering critical TPS damage) through maximizing the Shuttle's ascent performance margins to achieve ISS orbit, using the docked configuration to maximize inspection and repair capabilities, and flying protective attitudes following undocking from the ISS. However, NASA will continue to analyze the relative merit of different approaches to mitigating the risks identified by the *Columbia* Accident Investigation Board.

This approach to avoiding unnecessary risk has also led NASA to recognize that autonomous missions carry a higher risk than ISS missions. A brief summary of the additional risks associated with autonomous missions is described below:

1. *Lack of Significant Safe Haven*. The inability to provide a "safe haven" while inspection, repair, and potential rescue are undertaken creates additional risk in autonomous missions. On missions to the ISS it may be possible to extend time on orbit to mount a well-planned and -equipped rescue mission. NASA is continuing to study this contingency scenario. For autonomous missions, however, the crew would be limited to an additional on-orbit stay of no more than two to four weeks, depending on how remaining consumables are rationed. The Safe Haven concept is discussed in detail in SSP-3

2. *Unprecedented Double Workload for Ground Launch and Processing Teams*. Because the rescue window for an autonomous mission is only two to four weeks, NASA would be forced to process two vehicles for launch simultaneously to ensure timely rescue capability. Any processing delays to one vehicle would require a delay in the second vehicle. The launch countdown for the second launch would begin before the actual launch of the first vehicle. This short time period for assessment is a serious concern. It would require two highly complex processes to be carried out simultaneously, and it would not permit thorough assessment by the launch team, the flight control team, and the flight crew.

3. *No Changes to Cargo or Vehicle Feasible*. Because of the very short timeframe between the launch of the first vehicle and the requirement for a rescue flight, no significant changes could reasonably be made to the second vehicle. This means that it would not be feasible to change the cargo on the second Space Shuttle to support a repair to the first Shuttle, add additional rescue hardware, or make vehicle modifications to avoid whatever situation caused the need for a rescue attempt in the first place. Not having sufficient time to make the appropriate changes to the rescue vehicle or the cargo could add significant risk to the rescue flight crew or to crew transfer. The whole process would be under acute schedule pressure and undoubtedly many safety and operations waivers would be required.

4. *Rescue Mission*. Space Shuttles routinely dock with the ISS, and Soyuz evacuation procedures are supported by extensive training, analysis, and documentation. A rescue from the ISS, with multiple hatches, airlocks, and at least one other vehicle available (Soyuz), is much less complex and risky than that required by a stranded Space Shuttle being rescued by a second Space Shuttle. When NASA first evaluated free-space transfer of crew, which would be required to evacuate the Shuttle in an autonomous mission, many safety concerns were identified. This analysis would need to be done again, in greater detail, to identify all of the potential issues and safe solutions.

5. *TPS Repair*. NASA's current planned TPS repair method for an ISS-based repair uses the ISS robotic arm to stabilize an extravehicular activity (EVA) crew person over the worksite. This asset is not available for an autonomous mission, so NASA would have to finish development of an alternate method for stabilizing the crewmember. Such a concept is in development targeting 2006, when it will be needed for ISS-based repairs also. Solving this problem before 2006 represents a challenging undertaking.

NASA IMPLEMENTATION

Note: This section refers to inspection and repair during nominal Shuttle missions to the ISS.

NASA has greatly expanded the capabilities to detect debris liberation during ascent, to identify locations where debris may have originated, and to identify impact sites on the Orbiter TPS for evaluation. The ability to see debris liberated during ascent through the addition of high-speed cameras, aircraft-mounted cameras, and radar, complemented by the impact detection sensor system and suite of on-orbit inspection assets, will aid in providing the data required to ensure an effective inspection and, if necessary, repair of the Orbiter TPS.

NASA will use a combination of Space Shuttle and ISS assets to image the Shuttle TPS and identify and characterize any damage. These inspection assets and methods include the Orbiter Boom Sensor System (OBSS), the Shuttle Remote Manipulator System (SRMS), the Space Station Remote Manipulator System (SSRMS), an experimental wing leading edge (WLE) impact sensor detection system, and the R-bar pitch maneuver (RPM). Each inspection method provides a piece of information to improve insight into the conditions of the Orbiter TPS.

Evaluation of the imagery and data collected during ascent and on orbit will determine the need for further, focused inspection. NASA has established criteria for focused on-orbit inspections to evaluate the length, width, and depth of potential critical damage sites. These criteria are based on our expanded understanding of debris transport mechanisms and the capabilities of the Orbiter TPS. Plans are in place for further inspection, evaluation, and repair for tile or Reinforced Carbon-Carbon (RCC) damage that exceeds the damage criteria. Appropriate risk assessment of each potential damage site that exceeds the damage criteria will be conducted and presented to the Mission Management Team (MMT) for evaluation. NASA will use a TPS assessment process, drawing on the data collected through inspections to make recommendations on whether a repair is required or whether the TPS can be used as is. If a repair is necessary, NASA will use a TPS damage assessment process to determine which repair method is required to enable the Orbiter to withstand the aero-thermal environment of entry and landing. In the event a safe entry is not possible, NASA has also made plans to keep the Space Shuttle crew on the ISS and mount a rescue mission. However, the CSCS capability will not be used to justify flying an otherwise unsafe vehicle and will only be used in the most dire of situations.

For the first two flights, NASA's central objective will be to verify the performance of the integrated Shuttle system. As a result, inspection is one of our operational priorities. However, there is limited operational time available to inspect during any mission and conditions during inspection may not always be optimal. Inspections that take place early in the mission will detect damage from ascent debris, but may not find damage sustained while on orbit; for instance, damage from a potential micrometeoroid or orbital debris strike. Any focused inspections will be guided by the results of ascent imagery that should indicate any areas of potential concern, the initial OBSS scans, and crew camera photos. Transport, impact, and material analyses and tests performed in the past few months have provided a clear enough picture of the WLE and RCC's characteristics to allow NASA to make an informed risk trade for a practicable inspection plan. This inspection plan will be based on potential debris sources and impact likelihood, specific RCC panel capabilities, and laser dynamic range imager (LDRI) capabilities that have been demonstrated beyond its certified performance.

Detection/Inspection

In February 2004, the SSP established an Inspection Tiger Team to review all inspection capabilities and to develop a plan to integrate these capabilities before RTF. The tiger team succeeded in producing a comprehensive in-flight inspection, imagery analysis, and damage assessment strategy that will be implemented through the existing flight planning process. The best available cameras and laser sensors suitable for detecting critical damage in each TPS zone will be used in conjunction with digital still photographs taken from the ISS during the Orbiter's approach. The tiger team strategy also laid the foundation for a more refined impact sensor and imagery system following the first two successful flights. This plan is being enhanced to clearly establish criteria for transitioning from one suite of inspection capabilities to another and the timeline for these transitions.

Along with the work of the tiger team, the Shuttle Systems Engineering and Integration Office began development of a TPS Readiness Determination Operations Concept, which is documented in the Operations Integration Plan for TPS Assessment. This document specifies the process for collection, analysis, and integration of inspection data in a way that ensures effective and timely mission decision-making. The TPS assessment process begins with the activities leading up to launch and continues through post landing. The prelaunch process includes an approved configuration for imagery. Any deviation from this configuration will be presented at the Flight Readiness Review (FRR) and during the subsequent prelaunch MMT reviews. Additionally, the Ice/Debris Inspection Team will perform a series of prelaunch walk-downs of the pad and vehicle for potential debris sources and provide this information to the TPS assessment process.

During the mission, the TPS assessment process is divided into three steps: data collection, data processing, and Orbiter damage assessment. The data collection sources provide information on debris, debris trajectory, impact locations, damage, or depth of damage. During the data processing step, this information is analyzed to determine the health of the TPS. The Manager of Shuttle Systems Engineering and Integration will provide a daily status to the MMT of findings of the data collection and data processing. In addition, the findings are provided to the Orbiter Damage Assessment Team. During the Orbiter damage assessment step, NASA will determine where there is potential TPS damage and develop recommendations to the MMT on whether the damaged TPS is safe to fly as is or whether a repair is needed, as well as which type of repair is required.

Post landing, the TPS assessment process will continue with a walkdown of the Orbiter by the Ice/Debris Inspection Team, which will document observed TPS defects with photographs. The TPS assessment process concept has been exercised in several simulations.

Damage Threshold

NASA has defined the critical damage threshold for TPS Inspections. This is the ability to detect damage of 1 in. for tile around doors and 3 in. for acreage tile, and to detect cracks 0.020 in. × 2 in. for RCC. Through an extensive test program and analytical models developed to predict the capabilities of damaged tile and RCC, NASA has determined that damage smaller than this threshold should not result in increased risk to entry. With the combination of resources available at RTF, NASA will have the capability to detect this damage. However, the damage detection capability itself will not be certified prior to STS-114.

OBSS

The OBSS is an imaging system that consists of sensors on the end of a 50-ft boom structure. The system is installed on the starboard sill of the Orbiter payload bay (figure 6.4-1-1).It is the primary system used to inspect WLE RCC, and to obtain damage depth measurements of Orbiter TPS. The OBSS will carry a laser camera system and an LDRI for damage depth detection and will be used in conjunction with the SRMS for inspection. The video from the OBSS is recorded on board the Shuttle and downlinked via the Orbiter communications system. The data will be processed and analyzed on the ground as part of the TPS assessment process.

For STS-114, OBSS operations are planned on the second and fourth crew flight day. On the second flight day, prior to docking with the ISS, the crew will use the OBSS to inspect the WLE RCC and nose cap. Current plans call for OBSS scans of the underside and apex of the 22 RCC panels on each wing at a rate of no more than 1 meter/minute. Tests of the OBSS indicate that it should be able to detect critical damage at this scan speed. These data will be fed into the TPS assessment process for Orbiter damage assessment. On the fourth flight day, the crew will use the OBSS as demonstration of capability and/or to inspect areas identified through the TPS assessment process as areas of concern. The OBSS can be used to further inspect any suspect TPS area identified through the TPS assessment process, either before or after the Orbiter docks to the ISS. In addition, the OBSS will have the capability to support an EVA crewmember if needed to support inspection and repair activities.

ISS Imagery During RPM

The primary method of inspecting the acreage tile across the bottom of the Orbiter will be still photo imagery taken by the ISS crew as the Orbiter approaches for docking. This maneuver, the RPM has been developed and is being practiced by Shuttle flight crews in the simulator (figure 6.4-1-2) The Orbiter will pause its approach to the ISS

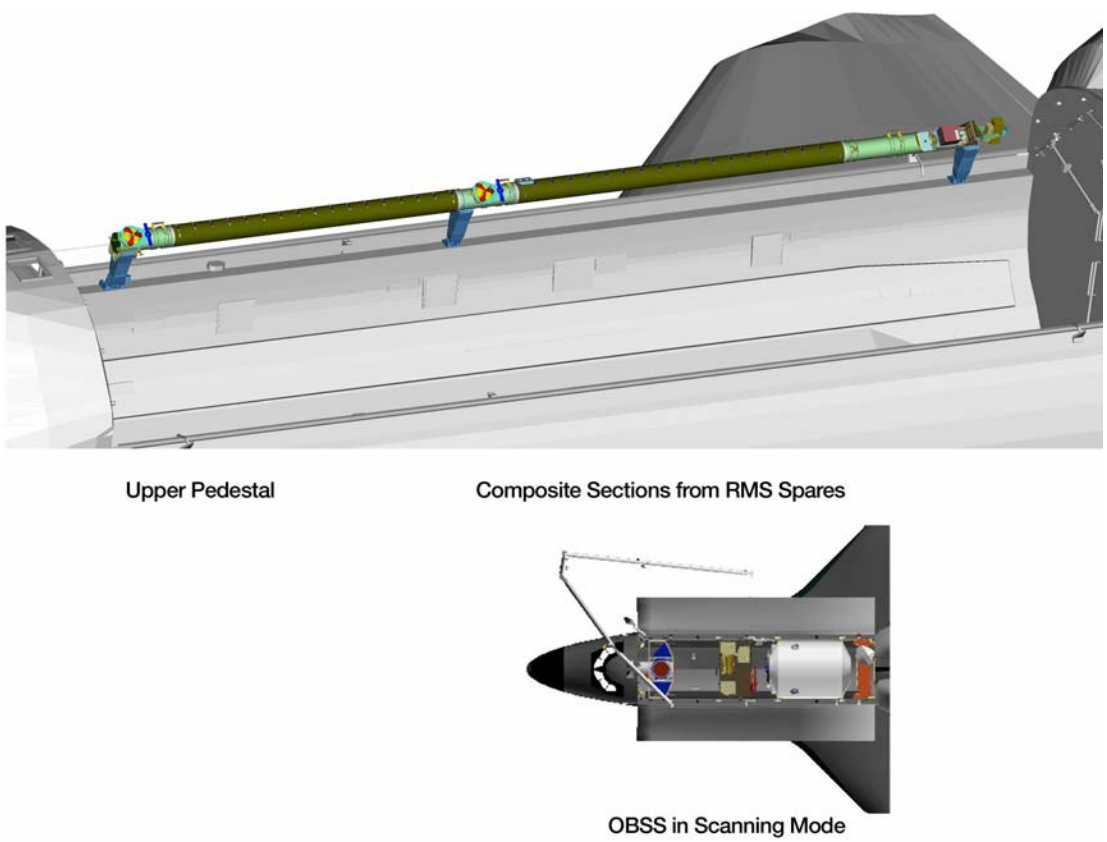
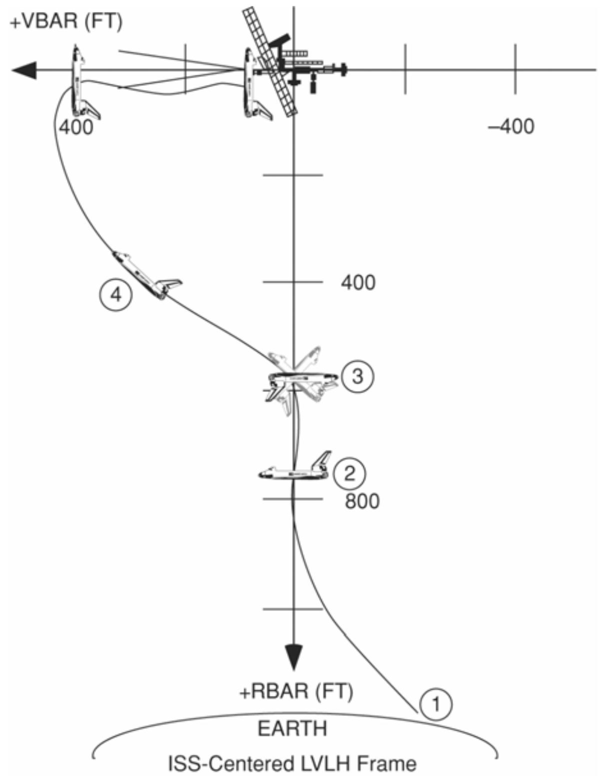


Figure 6.4-1-1. Orbiter Boom Sensor System.



	EVENT
1	1000 FT RANGE RATE GATE (RDOT = –1.3 FPS) TRANSITION TO LOWZ
2	ORBITER ACQUIRES RBAR
3	600 FT (RDOT = –0.1 FPS BEGIN 1 DEG/SEC POSITIVE PITCH AUTO MNVR: MODE TO FREE DRIFT TO PROTECT ISS FROM ORBITER PLUME LOADS AND CONTAMINATION
	ISS PHOTOGRAPHIC SURVEY OPPORTUNITY FROM U.S. LAB WINDOW
	RESUME ATTITUDE HOLD AS ORBITER RETURNS TO RBAR ATTITUDE AND PILOT BACK TO NOMINAL APPROACH PROFILE
4	TORVA (TWICE ORBITAL RATE RBAR TO VBAR APPROACH)

Figure 6.4-1-2. Orbiter RPM for inspection and approach to ISS.

when it is 600 ft away and pitch over to present its underside toward the ISS. The ISS crew will take overlapping high-resolution digital images of the Orbiter's acreage tile and downlink them to the ground. Areas of concern identified by the RPM photos will be re-inspected for more detail (such as damage depth) while the Orbiter is docked to the ISS.

The cameras used to photograph the Orbiter have the capability to detect critical damage in almost all areas on ISS flights. However, the image resolution is not sufficient for all TPS areas and cannot provide depth of impact information. NASA's analysis suggests that the 400mm photos should have an analytical resolution of 3 in. on normal surfaces and the 800mm photos should have a 1-in. analytical resolution.

Other Imagery Assets

Other imagery assets include the SRMS, the SSRMS, and other digital camera assets on board the Shuttle or the ISS. The SRMS and SSRMS can inspect areas of the Orbiter TPS within their operational reach, such as the crew cabin area, forward lower surface, or vertical tail, using their closed circuit television camera systems. Other digital assets include the still cameras available to EVA crewmembers in the event an EVA inspection is required. EVA inspections are not planned and will be used as a last resort backup for the other inspection methods.

WLE Impact Detection System

The WLE Impact Detection System was developed from an existing technology that had been previously flown as an experiment on the Shuttle. Initially, NASA hoped to include WLE sensors as a key element of our ability to detect damage. However, this system has not been flight-tested, so its capability is yet to be determined. These sensors may be used primarily as a "pointing" device to cue TPS areas needing further inspection by the OBSS.

The WLE sensor system is composed of accelerometer and temperature sensors located in both of the wing cavities and attached to the wing spar behind the RCC. The WLE sensor system data are collected during ascent and while on orbit and are downlinked to the ground via the Orbiter communications system. These data will help identify possible debris impact areas in the vicinity of the WLE RCC panels. In the event an impact is detected, engineers can determine the location of the sensor(s) that measured the impact and, through the TPS assessment process, recommend a more focused inspection of the suspect area later in the mission. Due to the limited battery life, there is a finite period of time for impact detection using this system. These sensor will be flown on STS-114 and subsequent flights. Long term, the power input will be changed from the current battery system to being powered directly from the on-board fuel cells. This power configuration change will allow the sensor system to provide impact detection throughout the mission.

Repair

The Space Flight Leadership Council determined that certified TPS repair capability would not be held as a constraint to RTF. As a result, STS-114 will launch with the repair capabilities that are available at FRR.

Also critical to flight safety is the development of a useful analytical tool to determine whether damage sustained is safe for entry or requires repair, and whether an attempted repair will render the Orbiter safe for entry. Damage assessment tools used during the mission are the same as those used for preflight inspection criteria validation and include aero-heating environments, cavity heating augmentation factors, damaged tile assessment tools, and structural analysis tools. There are two elements to determine whether damage sustained is safe for entry. The first is a use-as-is assessment to determine whether a repair should be attempted. The second is a follow-on assessment to determine whether any repairs attempted have made the Orbiter safe for entry. This process is documented in the Operation Integration Plan for TPS Assessment.

TPS Repair Access

The EVA crew will use either the SRMS or the SSRMS to gain access to repair sites on the Orbiter; when necessary, they may also use the OBSS. For repair areas that the SRMS or SSRMS cannot access, NASA has developed a combined SRMS and SSRMS "flip around" operation, called the Orbiter repair maneuver (ORM), to allow TPS repairs while the Shuttle is docked to the ISS. The ORM involves turning the Shuttle into a belly-up position that provides arm access to the repair site. As depicted in figure 6.4-1-3, the SRMS grapples the ISS while docked. The docking mechanism hooks are then opened, and the SRMS rotates the Orbiter into a position that presents the lower surface to the ISS. The EVA crew then works from the SSRMS, with the SSRMS used to position the crewmember to reach any TPS surface needing repair.

NASA is developing EVA tools and techniques for TPS repair. NASA has already developed prototype specialized tools for applying and curing TPS repair materials. We are also beginning to develop new and innovative EVA

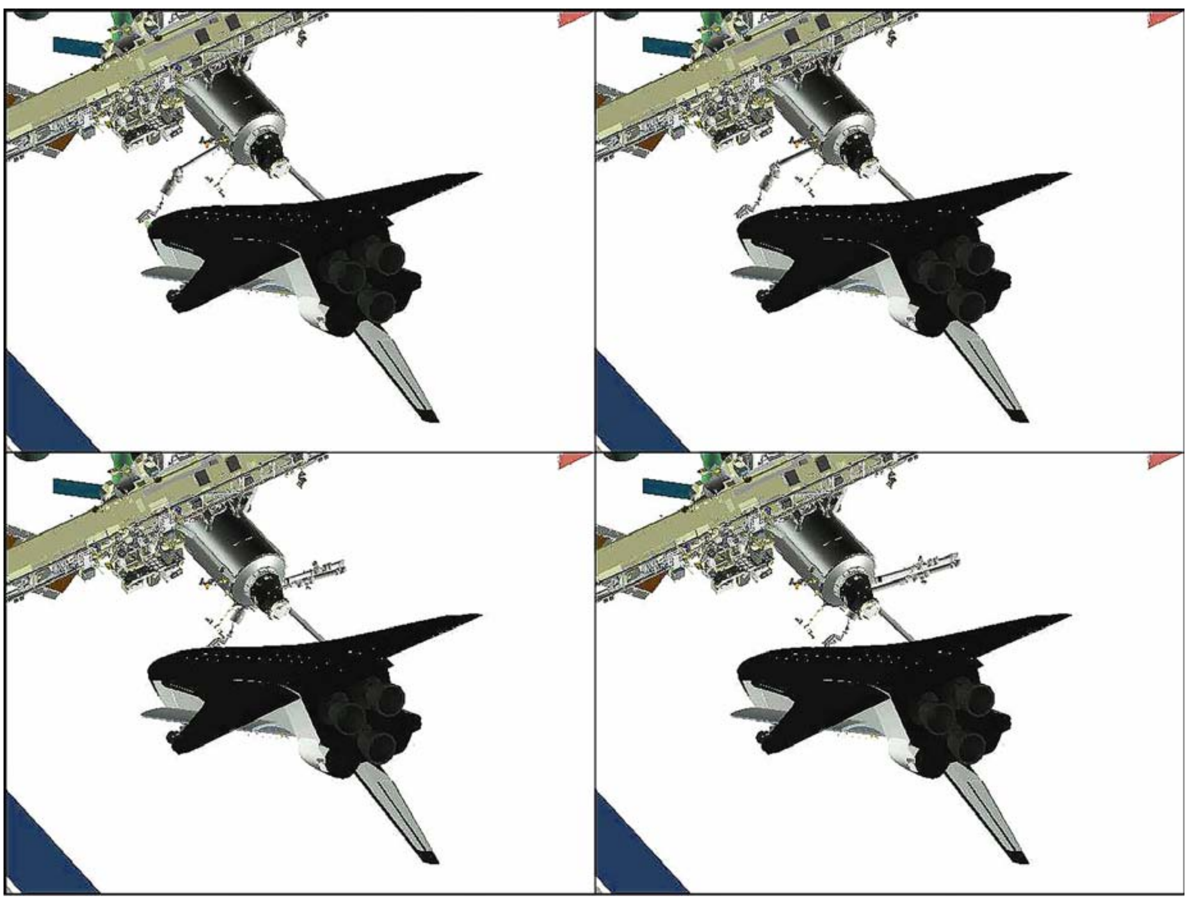


Figure 6.4-1-3. Proposed method for providing EVA access during TPS repair on an ISS flight.

techniques for working with the fragile Shuttle TPS system while ensuring that crew safety is maintained. EVAs for TPS repair represent a significant challenge; the experiences gained through the numerous complex ISS construction tasks performed over the past several years are contributing to our ability to meet this challenge.

After the repair, the SRMS maneuvers the Orbiter back into position and reattaches the Orbiter to the docking mechanism. This technique provides access to all TPS surfaces without the need for new equipment. The procedure will work through ISS flight 1J (which will add the Japanese Experiment Module to the ISS on-orbit assembly). After ISS flight 1J, the ISS grapple fixture required to support this technique will be blocked, and new TPS repair access techniques will need to be developed.

RCC Repair

NASA is evaluating RCC repair concepts across six NASA centers, 11 contractors, and the United States Air Force Research Laboratory. Although we are aggressively pursuing RCC repair, it is too early in development to forecast a completion date. The main challenges to repairing RCC are maintaining a bond to the RCC coating during entry heating and meeting very small edge step requirements.

The RCC repair project is pursuing two complementary repair concepts—plug repair and crack repair—that together will enable repair of some RCC damage. Plug repair consists of a cover plate intended to repair medium-sized holes in the WLE from 1 in. to 6 in. in diameter. Crack repair uses a non-oxide experimental adhesive (NOAX) material application intended to fill cracks and missing coating areas in the WLE. Both concepts are expected to have limitations in terms of damage characteristics, damage location, and testing/analysis.

Complimenting plug repair, step drills that could penetrate through RCC are being developed for STS-114. The step drills will provide additional capability to repair RCC holes smaller than 1 in. in diameter. NASA has also initiated an effort to repair medium-sized holes with a flexible patch concept. This flexible patch would be directly applied over holes and cracks found on RCC panels. However, due to the relatively low technology maturity level of this concept in comparison with plug and crack repair, it will not be pursued for RTF. Schedules for design, development, testing, evaluation, and production of these concepts are in work.

A fourth repair concept, RCC rigid overwrap, encountered problems during development and was shown to be infeasible to implement in the near term; as a result, it was deleted from consideration for RTF. NASA is continuing research and development on a long-term, more flexible RCC repair technique for holes greater than 6 in. in diameter.

Tile Repair

Past attempts to develop a usable tile repair capability had been unsuccessful because of the lack of technical maturity in the area. However, recent advances in materials provided the possibility that the capability could be developed before NASA returned to flight.

NASA will have limited, uncertified tile repair capability ready for RTF. This capability will include an emittance wash application that can repair shallow damage, may also include a cure in place ablator (CIPA) repair material and a CIPA applicator designed to repair larger damage, and potentially other tile repair methods still under development (such as tile repair overlay). Repair materials will be flown on STS-114 and STS-121. Demonstrations will be conducted for emittance wash on STS-114 and CIPA demonstrations are planned for STS-121.

Current repair development challenges center around dispensing the CIPA repair material with consistency. The CIPA is an STA-54 ablator, a two-part material that must be mixed together. Both the material and the applicator have encountered significant challenges during development. Most significant is recurrent bubbling in the material. NASA has been unable to determine the root cause of the bubbling, or to adequately and consistently characterize its severity. Recent successful ground tests show that bubbling does not compromise the thermal protection capabilities of the STA-54 material, but testing in the actual on-orbit environment is needed to confirm this finding. After additional developmental testing, a review was held to assess the likelihood that the design baseline for analytical tools, repair materials, EVA tools, and operational techniques would satisfy the system requirements. While substantial progress was apparent, the technical and schedule risks associated with material bubbling remained. Two CIPA applicators will be flown on STS-114, but will not be demonstrated.

The emittance wash is a silicon-carbide material mixed with a carrier material. It provides an emissive coating to the tiles, which is used to prevent small gouges in the tile from burning through to deeper holes. This keeps the damage shallow and prevents cavity heating effects, preserving the insulating capability of the tile. The emittance wash can be used as a standalone tile repair capability and may also be used to prime and seal CIPA repairs to the tiles.

TPS Repair Development Test Objective on STS-114

On STS-114 and STS-121, hardware with simulated tile and RCC damage will be flown in the the payload bay to enable the crew to practice tile and RCC repair techniques. During STS-114, the following will be demonstrated during an EVA:

- Tile repair emittance wash application
- RCC repair NOAX crack repair material evaluation

Also during STS-114, an intravehicular activity demonstration of the mechanical aspects of the RCC plug repair will be conducted.

STATUS

The following actions have been completed:

- Quantified SRMS, SSRMS, and ISS digital still camera inspection resolution
- Feasibility analyses for docked repair technique using SRMS and SSRMS
- Air-bearing floor test of overall boom to SRMS interface
- OBSS conceptual development, design requirements, and preliminary design review, systems design review, initial OV-103 vehicle integration testing at Kennedy Space Center with both sensors
- Engineering assessment for lower surface radio frequency communication during EVA repair
- Simplified Aid for EVA Rescue technique conceptual development and testing
- Feasibility testing on tile repair material
- Tile repair material transition from concept development to validation tests
- 1-G suited tests on tile repair technique
- Initial KC-135 tile repair technique evaluations
- Vacuum dispense and cure of the tile repair material with key components of the EVA applicator
- Review of all Shuttle systems for compatibility with the docking repair scenario
- Inspection Tiger Team strategy formulated
- Down-selected to two complementary RCC repair techniques for further development (Plug Repair, Crack Repair), with the elimination of Rigid Wrap Repair for RTF
- Developed the inspection and repair of the RCC and tile operations concept (figure 6.1-4-4)
- The digital cameras that ISS crew will use to photograph the Shuttle TPS were launched on a Russian Progress vehicle and are now on board the ISS

NASA will launch STS-114 with the repair capabilities that are available at time of the FRR in late April 2005. Currently, we anticipate these will include a limited capability to repair minor tile damage and small- to medium-sized RCC damage. Also critical to flight safety is the development of a useful analytical tool to determine whether damage sustained is safe for entry or requires repair, and whether any repairs attempted have rendered the Orbiter safe.

FORWARD WORK

NASA is in the process of certifying the OBSS hardware and finalizing operational procedures. There is still some schedule risk in OBSS development. Certification may not be complete by RTF. As a result, the Orbiter Project has developed a phased approach to verification and certification to meet the RTF requirements.

In addition to planned TPS repair capability, special on-orbit tests are under consideration for STS-114 to further evaluate TPS repair materials, tools, and techniques.

Final detailed analyses are in work to optimize Shuttle attitude control and re-docking methods during repair.

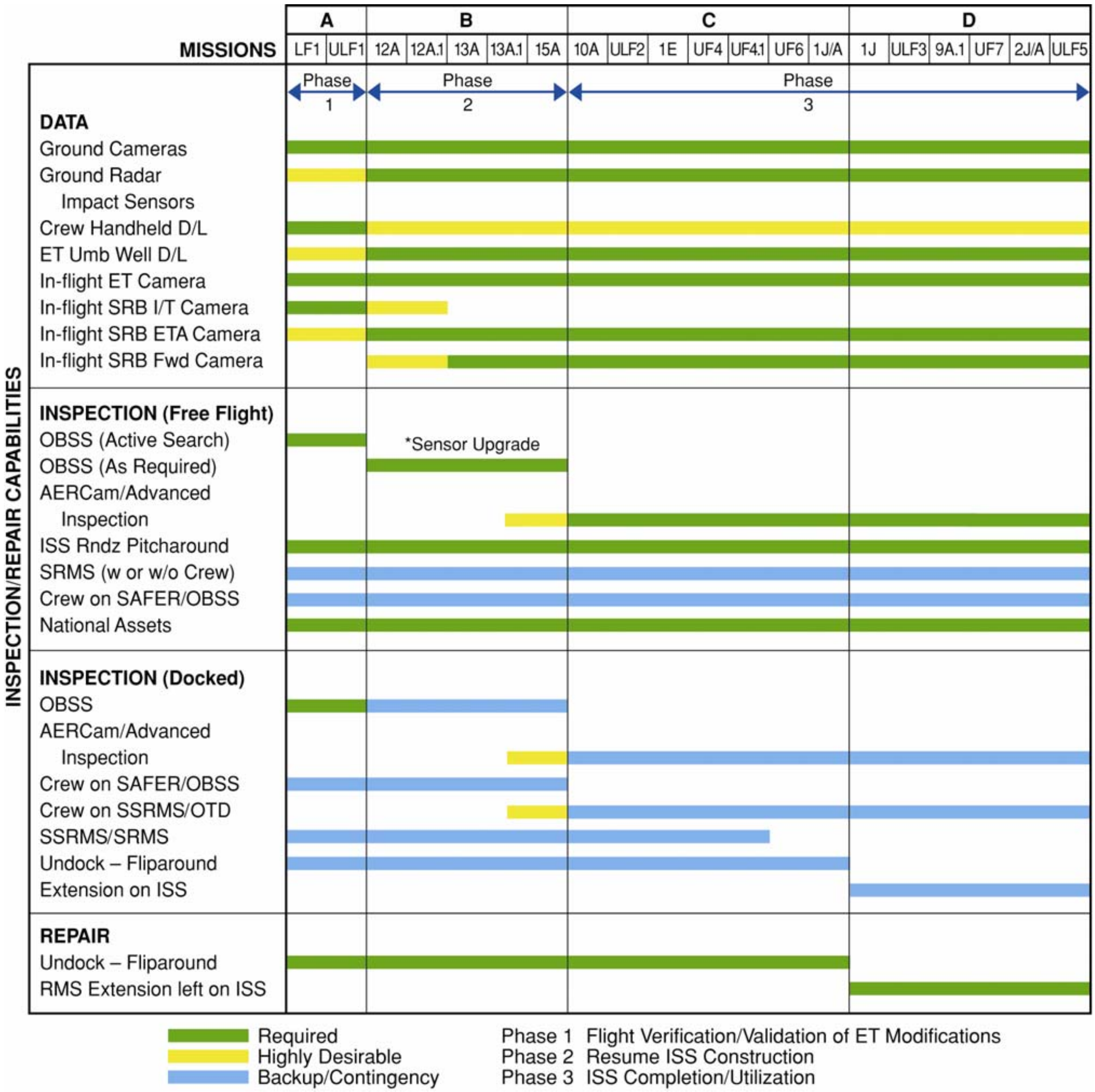


Figure 6.4-1-4. Integrated operations concepts for inspection and repair.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Jul 03 (Completed)	1-G suited and vacuum testing begins on tile repair technique
SSP	Aug 03 (Completed)	Generic crew and flight controller training begins on inspection maneuver during approach to ISS
SSP	Aug 03 (Completed)	KC-135 testing of tile repair technique
SSP	Oct 03 (Completed)	Start of RCC repair concept screening tests
SSP	Dec 03 (Completed)	Tile repair material selection
SSP	Jun 04 (Completed)	Baseline ISS in-flight repair technique requirements and damage criteria
SSP	Sep 04 (Completed)	Initial human thermal-vacuum, end-to-end tile repair tests
JSC/Mission Operations Directorate	Oct 04 (Completed)	Formal procedure development complete for inspection and repair
SSP	TBD	Additional human thermal-vacuum, end-to-end tile repair tests
SSP	TBD	Tile repair materials and tools delivery
SSP	Jan 05 (Completed)	RCC repair concept downselect
SSP and ISS Program	Apr 05	All modeling and systems analyses complete for docked repair technique
SSP	Apr 05	Tile repair materials and tools delivery
SSP	STS-114	On-orbit test of TPS repair tools and process

Columbia Accident Investigation Board

Recommendation 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]

Note: The Stafford-Covey Return to Flight Task Group held a plenary session on December 15, 2004, and NASA's progress toward answering this recommendation was reviewed. The Task Group agreed the actions taken were sufficient to conditionally close this recommendation.

BACKGROUND

NASA's evaluation of the STS-107 ascent debris impact was hampered by the lack of high-resolution, high-speed ground cameras. In response to this, tracking camera assets at the Kennedy Space Center (KSC) (figure 3.4-1-1) and on the Air Force Eastern Range will be upgraded to provide improved data during Shuttle ascent.

Multiple views of the Shuttle's ascent from varying angles and ranges provide important data for engineering assessment and discovery of unexpected anomalies. These data points are important for validating and improving Shuttle performance, but less useful for pinpointing the exact location of potential damage.

Ground cameras provide visual data suitable for detailed analysis of vehicle performance and configuration from prelaunch through Solid Rocket Booster separation. Images can be used to assess debris shed in flight, including origin, size, and trajectory. In addition to providing information about debris, the images will provide detailed information on the Shuttle systems used for trend analysis that will allow us to further improve the Shuttle. Together, these help us to identify unknown environments or technical anomalies that might pose a risk to the Shuttle.

NASA IMPLEMENTATION

NASA is developing a suite of improved ground- and airborne cameras that fully satisfies this Recommendation. This improved suite of ground cameras will maximize our ability to capture three complementary views of the Shuttle and provide the Space Shuttle Program (SSP) with engineering data to give us a better and continuing understanding of the ascent environment and the performance of the Shuttle hardware elements within this environment. Ground imagery may also allow us to detect ascent debris and identify potential damage to the Orbiter for on-orbit assessment. There are four types of imagery that NASA will acquire from the ground cameras: primary imagery—film images used as the primary analysis tools for launch and ascent operations; fall-back imagery—backup imagery for use when the primary imagery is unavailable; quick-look imagery—imagery provided to the Image Analysis labs shortly after launch for initial assessments; and tracker imagery—images used to guide the camera tracking mounts and for analysis when needed. Any anomalous situations identified in the post-ascent "quick-look" assessments will be used to optimize the on-orbit inspections described in Recommendation 6.4-1.

NASA has increased the total number of ground cameras and added additional short-, medium-, and long-range camera sites, including nine new quick-look locations.

Figure 3.4-1-1. Typical KSC long-range tracker.

Since all future Shuttle missions are planned to the International Space Station, the locations of the new cameras and trackers are optimized for 51.6-degree-inclination launches. Previously, camera coverage was limited by a generic configuration originally designed for the full range of possible launch inclinations and ascent tracks. NASA has also added High-Definition Television (HDTV) serial digital cameras and 35mm and 16 mm motion picture cameras for quick-look and fall-back imagery, respectively. In addition, NASA has taken steps to improve the underlying infrastructure for distributing and analyzing the additional photo imagery obtained from ground cameras. Some of this infrastructure is built on the system configured to support the distribution and images and engineering data in support of the *Columbia* accident investigation.

System Configuration

NASA divides the Shuttle ascent into three overlapping periods with different imaging requirements. These time periods provide for steps in lens focal lengths to improve image resolution as the vehicle moves away from each camera location:

- Short-range images (T-10 seconds through T+57 seconds)
- Medium-range images (T-7 seconds through T+100 seconds)
- Long-range trackers (T-7 or vehicle acquisition through T+165 seconds)

For short-range imaging, NASA has two Photographic Optic Control Systems (POCS), a primary and a backup, to control the fixed-film cameras at the launch pad, Shuttle Landing Facility, and the remote areas of KSC. There is significant redundancy in this system: each POCS has the capability of controlling up to 512 individual cameras at a rate of 400 frames per second. Currently, there are approximately 75 cameras positioned for launch photography. POCS redundancy is also provided by multiple sets of command and control hardware and by multiple overlapping views, rather than through backup cameras. The POCS are a part of the Expanded Photographic Optic Control Center (EPOCC). EPOCC is the hub for the ground camera system.

The medium- and long-range tracking devices will be on mobile platforms (e.g., Kineto Tracking Mount (KTM)), allowing them to be positioned optimally for each flight. The three trackers on the launch pad will be controlled with the Pad Tracker System (PTS). PTS is a KSC-designed and -built system that provides both film and video imagery. It has multiple sets of command and control hardware to provide system redundancy. Each of the medium- and long-range tracking cameras is independent, assuring that no single failure can disable all of the trackers. Further, each of the film cameras on the trackers uses HDTV as a backup. For each flight, NASA will optimize the camera configuration, evaluating the locations of the cameras to ensure that the images provide the necessary resolution and coverage.

The planned locations at Launch Complex 39-B for short, medium-, and long-range tracking cameras are as shown in figures 3.4-1-2, 3.4-1-3, and 3.4-1.4, respectively. As studies improve the understanding of vehicle coverage during ascent, these positions may change. Existing

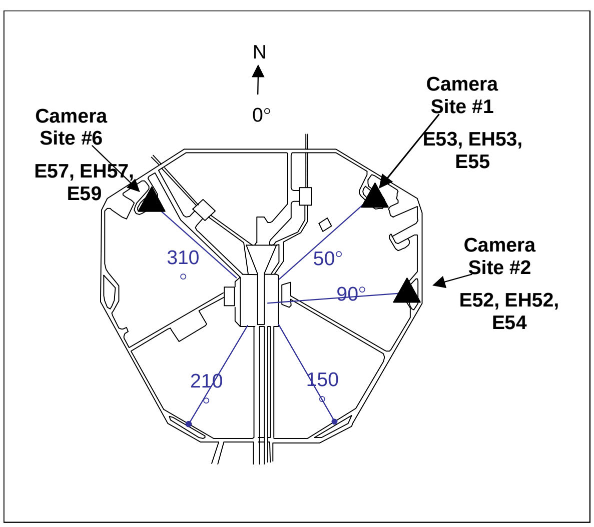


Figure 3.4-1-2. Short-range camera sites.

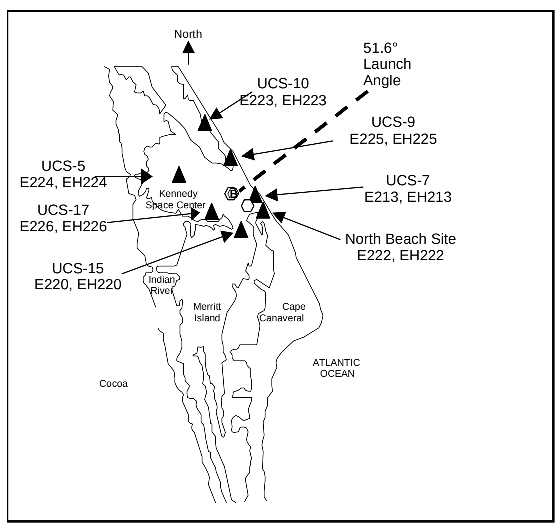


Figure 3.4-1-3. Medium-range tracker sites.

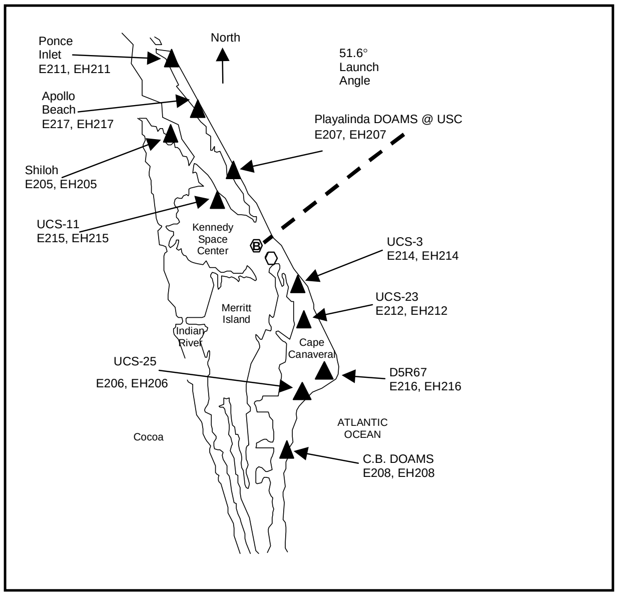


Figure 3.4-1-4. Long-range tracker sites.

Figure 3.4-1-5. WB-57 aircraft.

cameras will be moved, modernized, and augmented to comply with new requirements.

In addition to ground cameras, NASA has approved the development and implementation of an aircraft-based imaging system known as the WB-57 Ascent Video Experiment (WAVE) to provide both ascent and entry imagery. The use of an airborne imaging system will provide opportunities to better observe the vehicle during days of heavier cloud cover and in areas obscured from ground cameras by the exhaust plume following launch.

The primary hardware for the WAVE consists of a 32-in. ball turret system mounted on the nose of two WB-57 aircraft (figure 3.4-1-5). The use of two aircraft flying at an altitude of 60,000 ft will allow a wide range of coverage with each airplane providing imagery over a 400-mi path. The entry imaging program will involve the use of aircraft to provide imagery during the later stages of entry. The WAVE ball turret houses an optical bench that provides a location for installation of multiple camera systems (High-Definition Television (HDTV), infrared). The optics consist of a 4.2-m fixed focal length lens with an 11-in. aperture, and the system can be operated in both auto track and manual modes.

WAVE will be used on an experimental basis during the first two Space Shuttle flights following return to flight (RTF). Based on an analysis of the system's performance and quality of the products obtained, following these two flights NASA will make the decision on whether to continue use of this system on future flights. Critical Design Review for the WAVE was completed on July 1, 2004.

Although the ground cameras provide important engineering data for the Shuttle, they cannot have the resolution and coverage necessary to definitively establish that the Orbiter has suffered no ascent debris damage. No real-time decisions will be based on ground imagery data. Rather, the comprehensive assessments of Orbiter impacts and damage necessary to ensure the safety of the vehicle and crew will be conducted using on-orbit inspection and analysis.

NASA's analysis suggests that this upgraded suite of ground and airborne cameras will significantly improve NASA's ability to obtain three useful views of each Shuttle launch, particularly in conditions of limited cloud cover.

Launch Requirements

NASA is optimizing our launch requirements and procedures to support our ability to capture three useful views of the Shuttle, allowing us to conduct engineering analysis of the ascent environment. Initially, NASA will launch in daylight to maximize our ability to capture the most useful ground ascent imagery. Camera and tracker operability and readiness to support launch will be ensured by a new set of prelaunch equipment and data system checks that will be conducted in the days prior to liftoff. These checkouts will be documented in the Operations and Maintenance Requirements and Specifications Document with a final system status reported to the Launch Director at T-20 minutes. In addition, specific launch commit criteria (LCC) have been added for those critical control systems and data collection nodes for which a power failure would prevent the operation of multiple cameras or disrupt our ability to collect and analyze the data in a timely fashion. The camera LCC will be tracked to the T-9 minute milestone, and the countdown will not be continued if the criteria are not satisfied.

With the additional cameras and trackers that will be available at RTF, NASA has provided sufficient redundancy in the system to allow us to gather ample data and maintain three useful views—even with the loss of an individual camera or tracker. As a result, it is not necessary to track the status of each individual camera and tracker after the final operability checks. This enhances overall Shuttle safety by removing an unnecessary item for status tracking during the critical terminal countdown, allowing the Launch Control Team to concentrate on the many remaining key safety parameters. The LCCs remaining until the T-9 minute milestone protect the critical control systems and data collection nodes whose failure might prevent us from obtaining the engineering data necessary to assess vehicle health and function during ascent. For instance, the LCC will require that at least one POCS be functional at T-9 minutes, and that the overall system be stable and operating.

NASA has also confirmed that the existing LCCs related to weather constraints dictated by Eastern Range Safety satisfy the camera coverage requirements. NASA conducted detailed meteorological studies using Cape weather histories, which concluded that current Shuttle launch weather requirements, coupled with the wide geographic area covered by the ground camera suite and the airborne assets, adequately protect our ability to capture sufficient views of the Shuttle during ascent. The weather LCCs balance launch probability, including the need to avoid potentially dangerous launch aborts, against the need to have adequate camera coverage of ascent. The extensive revitalization of the ground camera system accomplished since the *Columbia* accident provides the redundancy that makes such an approach viable and appropriate.

STATUS

The Program Requirements Control Board (PRCB) approved an integrated suite of imagery assets that will provide the SSP with the engineering data necessary to validate the performance of the External Tank (ET) and other Shuttle systems, detect ascent debris, and identify and characterize damage to the Orbiter. On August 12, 2004, the PRCB approved funding for the camera suite, to include procurement and sustaining operations. The decision package included the deletion of several long- and medium-range cameras after the first two re-flights, contingent on clearing the ET and understanding the ascent debris environment.

NASA has begun shipping the 14 existing trackers to White Sands Missile Range for refurbishment. This work will be ongoing until refurbishment of all trackers is complete in 2009. Trackers and optics will be borrowed from other ranges to support the first two launches. NASA has also approved funding to procure additional spare mounts, as well as to fund studies on additional capability in the areas of infrared and ultraviolet imagery, adaptive optics, and high-speed digital video, and in the rapid transmission of large data files for engineering analysis. Procurement of new trackers will begin in February 2006. Procurement of optics is in process now.

NASA has doubled the total number of camera sites from 10 to 20, each with two or more cameras. At RTF, NASA will have three short-range camera sites around the perimeter of the launch pad; six medium-range camera sites, one at the Shuttle Launch Facility; and 10 long-range camera sites. To accommodate the enhanced imagery, we will install high-volume data lines for rapid image distribution and improve KSC's image analysis capabilities.

NASA is also procuring additional cameras to provide increased redundancy and refurbishing existing cameras. NASA has ordered 35 camera lenses to supplement the existing inventory and has purchased two KTM Digital Control Chassis to improve KTM reliability and performance. In addition, NASA has procured 24 HDTV cameras to improve our quick-look capabilities.

The U.S. Air Force-owned optics for the Cocoa Beach, Florida, camera (the "fuzzy camera" on STS-107) have been returned to the vendor for repair. We have completed an evaluation on current and additional camera locations, and refined the requirements for camera sites. Additional sites have been picked and are documented in the Launch and Landing Program Requirements Document 2000, sections 2800 and 3120. Additional operator training will be provided to improve tracking, especially in difficult weather conditions.

NASA is on track to implement the WAVE airborne camera systems to provide both ascent and entry imagery for RTF.

NASA's plan for use of ground-based wideband radar and ship-based Doppler radar to track ascent debris is addressed in Part 2 of this document under item SSP-12, Radar Coverage Capabilities and Requirements.

FORWARD WORK

The SSP is addressing hardware upgrades, operator training, and quality assurance of ground-based cameras according to the integrated imagery requirements assessment.

Prior to RTF, NASA will add redundant power sources to the command and control facility as part of our Ground Camera Upgrade to ensure greater redundancy in the fixed medium-/long-range camera system. NASA is also adding a third short-range tracker site prior to RTF.

NASA will continue to study improvements to its ground imagery capabilities following RTF. Additional enhancements may include replacing the HDTV and motion picture film cameras with High Speed Digital Video (HSDV) cameras and improving our image distribution and analysis capabilities to accommodate the HSDV content.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Aug 03 (Completed)	Program Approval of Ground Camera Upgrade Plan
SSP	Sep 03 (Completed)	Program Approval of funding for Ground Camera Upgrade Plan
SSP	Feb 04 (Completed)	Baseline Program Requirements Document Requirements for additional camera locations
SSP	May 04 (Completed)	Begin refurbishment of 14 existing trackers. Will be ongoing until all refurbishment of all trackers is complete (expected 2009) Trackers and optics will be borrowed from other ranges to support launch until the assets are delivered
SSP	Jul 04 (Completed)	Critical Design Review for WAVE airborne imaging system
SSP	Mar 05	Baseline revised Launch Commit Criteria
SSP	Mar 05	Install new optics and cameras
SSP	Multi-year Procurement	Acquire six additional trackers, optics, cameras, and spares for all systems. Trackers will be borrowed from other ranges to support launches until the vendor delivers the new KSC trackers

Columbia Accident Investigation Board

Recommendation 3.4-2

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

Note: The Stafford-Covey Return to Flight Task Group held a plenary session on December 15, 2004, and NASA's progress toward answering this recommendation was reviewed. The Task Group agreed the actions taken were sufficient to fully close this recommendation.

BACKGROUND

NASA agrees that it is critical to verify the performance of the External Tank (ET) modifications to control liberation of ascent debris. Real-time downlink of this information may help in the early identification of some risks to flight. The Space Shuttle currently has two on-board high-resolution cameras that photograph the ET after separation; however, the images from these cameras are available only postflight and are not downlinked to the Mission Control Center during the mission. Therefore, no real-time imaging of the ET is currently available to provide engineering insight into potential debris during the mission.

NASA IMPLEMENTATION

To provide the capability to downlink images of the ET after separation for analysis, NASA is replacing the 35mm film camera in the Orbiter umbilical well with a high-resolution digital camera and equipping the flight crew with a handheld digital still camera with a telephoto lens. Umbilical and handheld camera images will be downlinked after safe orbit operations are established. These images will be used for quick-look analysis by the Mission Management Team to determine if any ET anomalies exist that require additional on-orbit inspections (see Recommendation 6.4-1).

STATUS

The Space Shuttle Program (SSP) Requirements Control Board approved the Orbiter Project plan for installing the new digital camera in the Orbiter umbilical well for STS-114. NASA is completing test and verification of the performance of the new digital camera for the ET umbilical well. Based on results and analysis to date, NASA anticipates that the new umbilical well camera (figure 3.4-2-1) can be installed before return to flight. Orbiter design engineering and modifications to provide this capability are under way on all three vehicles. NASA will complete functional testing of the new digital camera in March 2005. The Orbiter umbilical well camera will be installed during Orbiter processing approximately six weeks prior to launch.

FORWARD WORK

None.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Sep 03 (Completed)	Initiate Orbiter umbilical well feasibility study
SSP	Apr 04 (Completed)	Complete preliminary design review/critical design review on approved hardware
SSP	May 04 (OV-103 Completed)	Begin Orbiter umbilical well camera wiring and support structure installation
SSP	Mar 05	Camera system functional testing completed
SSP	Launch –6 weeks	Install digital umbilical well camera

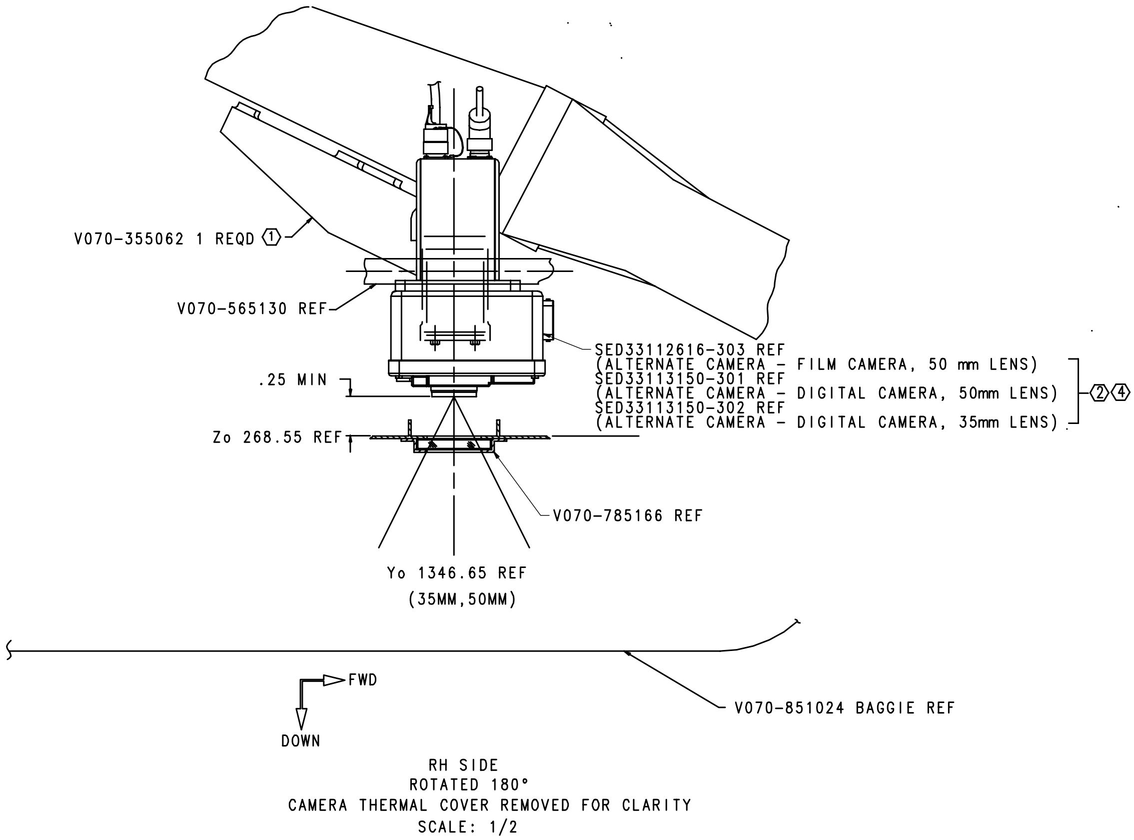


Figure 3.4-2-1. Schematic of umbilical well camera.

Columbia Accident Investigation Board

Recommendation 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]

BACKGROUND

The damage to the left wing of *Columbia* occurred shortly after liftoff, but went undetected for the entire mission. Although there was ground photographic evidence of debris impact, we were unaware of the extent of the damage. Therefore, NASA is adding on-vehicle cameras and sensors that will help to detect and assess damage.

NASA IMPLEMENTATION

For the first few missions after return to flight, NASA will use primarily on-orbit inspections to meet the requirement to assess the health and status of the Orbiter's Thermal Protection System. (Details on our on-orbit inspections can be found in Recommendation 6.4-1.) This is because the on-vehicle ascent imagery suite does not provide complete imagery of the underside of the Orbiter or guarantee detection of all potential impacts to the Orbiter. However, on-vehicle ascent imagery will be a valuable source of engineering, performance, and environments data and will be useful for understanding in-flight anomalies. NASA's long-term strategy will include improving on-vehicle ascent imagery.

For STS-114, NASA will have cameras on the External Tank (ET) liquid oxygen (LO_2) feedline fairing and the Solid Rocket Booster (SRB) -forward skirt. The ET LO_2 feedline fairing camera will take images of the ET bipod areas and the underside of the Shuttle fuselage and the right wing from liftoff through the first 15 minutes of flight. The new location of the ET camera will reduce the likelihood that its views will be obscured by the Booster Separation Module plume, a discrepancy observed on STS-112. These images will be transmitted real time to ground stations.

The SRB forward skirt cameras will take images from three seconds to 350 seconds after liftoff. These two cameras will look sideways at the ET intertank. The images from this location will be stored on the SRBs and available after the SRBs are recovered, approximately three days after launch.

Beginning with STS-115, we will introduce an additional complement of cameras on the SRBs: aft-looking cameras located on the SRB forward skirt and forward-looking cameras located on the SRB External Tank Attachment (ETA) Ring. Together, these additional cameras will provide comprehensive views Orbiter's underside during ascent.

STATUS

The Program Requirements Control Board approved the Level II requirements for the on-vehicle ascent camera system that will be implemented for return to flight.

FORWARD WORK

NASA will continue to research options to improve camera resolution, functionality in reduced lighting conditions, and alternate camera mounting configurations. In the meantime, work is proceeding on the new SRB camera designs and implementation of the approved ET and SRB cameras and wing leading edge sensors.

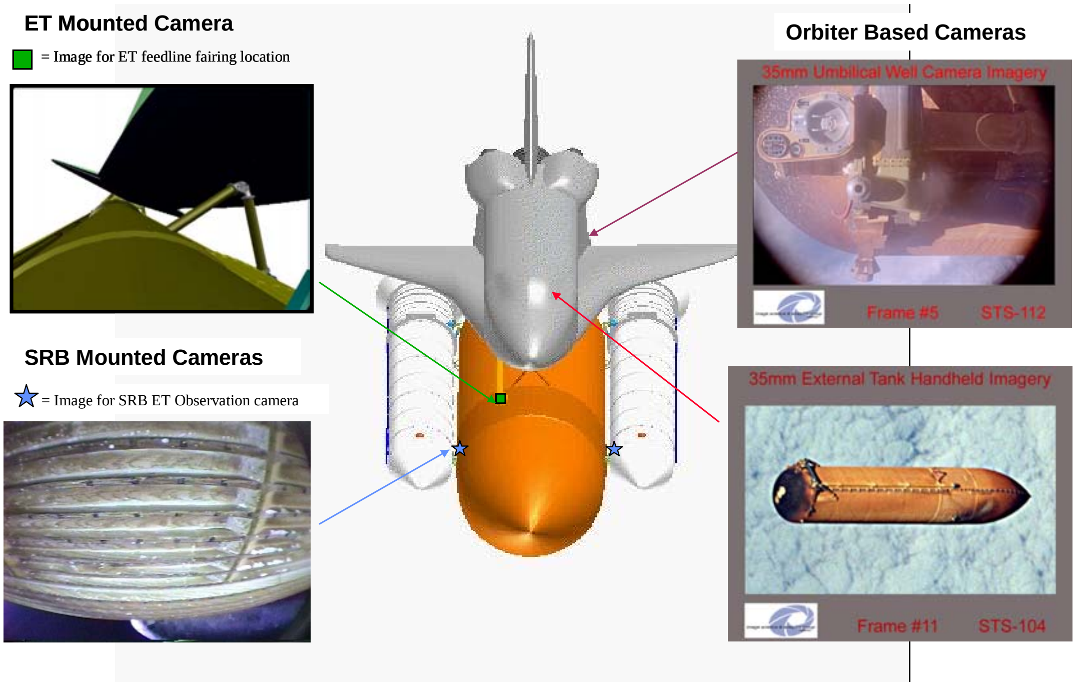


Figure 3.4-3-1. ET flight cameras (STS-114 configuration).

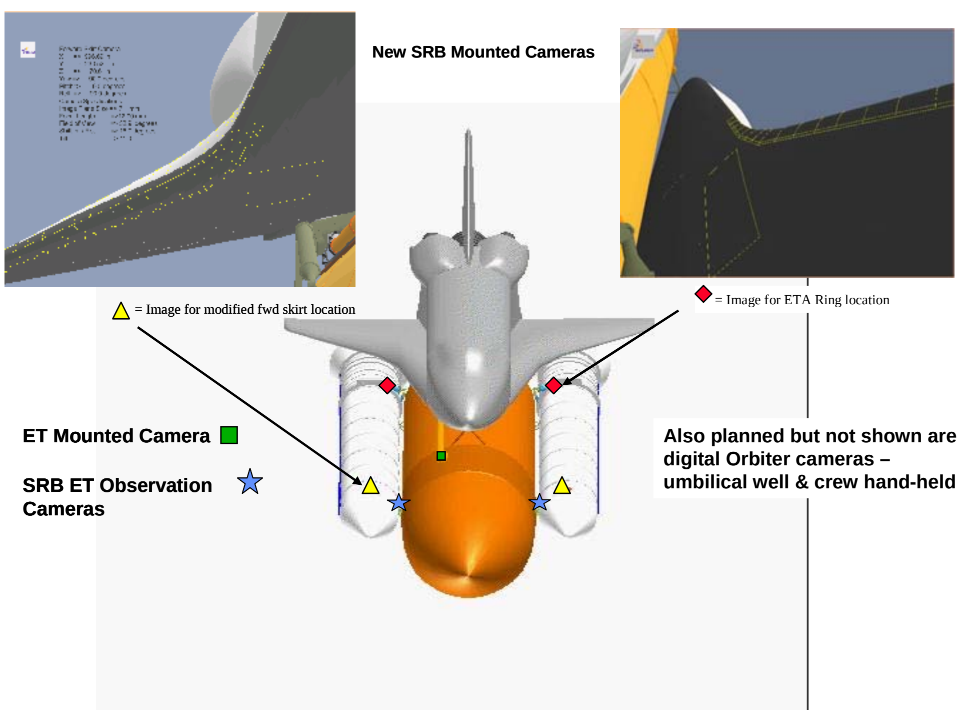


Figure 3.4-3-2. ET flight cameras (TBD configuration).

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Space Shuttle Program (SSP)	May 03 (Completed)	Start ET hardware modifications
SSP	Jul 03 (Completed)	Authority to proceed with ET LO_2 feedline and SRB forward skirt locations; implementation approval for ET camera
SSP	Mar 04 (Completed)	Systems Requirements Review
SSP	Jun 04 (Completed)	Begin ET camera installations
SSP	Oct 04 (Completed)	Begin SRB "ET Observation" camera installation
SSP	Apr 05	Review SRB camera enhancements for mission effectivity

Columbia Accident Investigation Board

Recommendation 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]

Note: The Stafford-Covey Return to Flight Task Group held a plenary session on December 15, 2004, and NASA's progress toward answering this recommendation was reviewed. The Task Group agreed the actions taken were sufficient to fully close this recommendation.

BACKGROUND

The *Columbia* Accident Investigation Board (CAIB) found, and NASA concurs, that the full capabilities of the United States to assess the condition of the *Columbia* during STS-107 should have been used but were not.

NASA IMPLEMENTATION

NASA has already concluded a Memorandum of Agreement with the National Imagery and Mapping Agency (subsequently renamed the National Geospatial-Intelligence Agency [NGA]) that provides for on-orbit assessment of the condition of each Orbiter vehicle as a standard requirement. In addition, NASA has initiated discussions with other agencies to explore the use of appropriate national assets to evaluate the condition of the Orbiter vehicle. Additional agreements have been developed and are in final review. The operational teams have developed standard operating procedures to implement agreements with the appropriate government agencies at the Headquarters level.

NASA has determined which positions/personnel will require access to data obtained from external sources. NASA will ensure that all personnel are familiar with the general capabilities available for on-orbit assessment and that the appropriate personnel are familiar with the means to gain access to that information. Over 70 percent of the requested clearances have been completed, and the remaining clearances are nearing completion.

Plans to demonstrate and train people per the new processes and procedures have been developed and will be exercised prior to the launch of STS-114. Testing and validation of these new processes and procedures have been accomplished in simulations conducted during the last six months of 2004. Since this action may involve receipt and handling of classified information, the appropriate security safeguards will be observed during its implementation.

In April 2004, the Stafford-Covey Return to Flight Task Group reviewed NASA's progress and agreed to conditionally close this recommendation. The full intent of CAIB Recommendation 6.3-2 has been met and full closure of this recommendation was achieved in December 2004.

FORWARD WORK

None.

SCHEDULE

An internal NASA process is being used to track clearances, training of personnel, and the process validation.

Columbia Accident Investigation Board

Recommendation 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.

Note: NASA is closing this recommendation through the formal Program Requirements Control Board process. The following summary details NASA's response to the recommendation and any additional work NASA intends to perform beyond the *Columbia* Accident Investigation Board (CAIB) recommendation.

BACKGROUND

The Modular Auxiliary Data System (MADS), which is also referred to in the CAIB Report as the "OEX recorder," is a platform for collecting engineering performance data. The MADS records data that provide the engineering community with information on the environment experienced by the Orbiter during ascent and entry, and with information on how the structures and systems responded to this environment. The repair and/or upgrade of sensors has not been a formal Space Shuttle Program (SSP) requirement because MADS was intended to be only a supplemental package, not used for flight critical decisions. This lack of formal requirements will be reassessed.

The MADS hardware is 1970's technology and is difficult to maintain. NASA has recognized the problem with its sustainability for some time. The available instrumentation hardware assets can only support the existing sensor suite in each Orbiter. If any additional sensors are required, their associated hardware must be procured.

NASA IMPLEMENTATION

The SSP agrees that MADS needs to be maintained. The SSP approved the incorporation of the MADS subsystem into the Program requirements documentation. The Instrumentation Problem Resolution Team (PRT) will be reviewing sensor requirements for various Orbiter systems to determine appropriate action for sensors. The PRT will also ensure proper maintenance of the current MADS hardware. NASA has acquired MADS wideband instrumentation tape and certified it for flight. This will extend the operational availability of the MADS recorder. NASA has also extended the recorder maintenance and skills retention contract with the MADS vendor, Sypris.

STATUS

The SSP will maintain the current MADS, including flight hardware and ground support equipment and sensor and data acquisition components for the remainder of the SSP. Space Shuttle retirement is projected to be at the end of the decade.

FORWARD WORK

The PRT and Logistics will continue performing supportability assessments on the MADS subsystem to determine maintenance strategy for continued support through the Space Shuttle's retirement.

SCHEDULE

Complete.

Columbia Accident Investigation Board

Recommendation 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.

Note: NASA is closing this recommendation through the formal Program Requirements Control Board (PRCB) process. The following summary details NASA's response to the recommendation and any additional work NASA intends to perform beyond the *Columbia* Accident Investigation Board (CAIB) recommendation.

BACKGROUND

The Modular Auxiliary Data System (MADS)* provides limited engineering performance and vehicle health information postflight. There are two aspects to this recommendation: (1) redesign for additional sensor information, and (2) redesign to provide the ability to select certain data to be recorded and/or telemetered to the ground during the mission. To meet these recommendations, a new system must be developed to replace MADS. The evaluation of this replacement is currently in progress to address system obsolescence issues and also provide additional capability.

The Space Shuttle Program (SSP) has also baselined a requirement to add additional vehicle health monitoring capability. These capabilities will increase the insight into the Orbiter's Thermal Protection System.

NASA IMPLEMENTATION

Initially, NASA planned to address the enhanced requirements for MADS through a new Vehicle Health Maintenance System (VHMS), which was part of the suite of upgrades comprising the Shuttle Service Life Extension Program. In January 2004, the Vision for Space Exploration was announced. The Vision refocused the mission of the SSP on support for and assembly of the International Space Station (ISS), and called for the retirement of the Space Shuttle following ISS assembly complete at the end of the decade. As a result of this program reorientation and the focus on returning safely to flight following the loss of the *Columbia* and her crew, the SSP reevaluated its Program priorities. As a part of this reevaluation, the Shuttle Program reviewed its commitment to the VHMS upgrade and determined that it was not a high-priority investment. VHMS would have expanded the Shuttle's capability to monitor new instrumentation and telemeter the resulting data, but did not address a specific safety concern. Rather it was designed to improve engineering insight into the Space Shuttle's condition during a mission.

Instead of developing and installing a new VHMS system, the Orbiter will be modified to provide low-rate MADS digital data available for downlink during on-orbit operations. These low-rate data include temperature, strain gauge, and pressure sensors already installed in unique locations specific to each Orbiter. In addition, there are other non-MADS instrumentation systems being proposed that will collect more vehicle health data. For instance, the Wing Leading Edge Sensor System (WLESS) will collect acceleration and temperature data along the Orbiter's right and left leading edge structure. Data from the WLESS will be available for downlink during on-orbit operations.

STATUS

The low-rate MADS digital data modification is installed on OV-104 (STS-121). The engineering and flight hardware has been delivered to Kennedy Space Center and is planned for installation into OV-103 (STS-116) and OV-105 Orbiter Major Modification (OMM) (STS-117). The WLESS is installed on OV-103 (STS-114). The installation is progressing for OV-104 (STS-121) and OV-105 OMM (STS-117).

FORWARD WORK

The SSP will continue to assess the data collection requirements for the integrated vehicle and the Orbiter, and will provide status updates to the PRCB.

*Note that the CAIB Report alternately refers to this as the OEX Recorder.

SCHEDULE

Complete.

Columbia Accident Investigation Board

Recommendation 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.

Note: With the establishment of a new national policy for U.S. space exploration in January 2004, the planned service life of the Space Shuttle was shortened. Following its return to flight, the Space Shuttle will be used to complete assembly of the International Space Station, planned for the end of the decade, and then the Shuttle will be retired. Due to the reduced service life, NASA's approach to complying with this recommendation has been appropriately adjusted. These actions were closed through the formal Program Requirements Control Board (PRCB) process. The following summary details NASA's response to the recommendation and any additional work NASA intends to perform beyond the *Columbia* Accident Investigation Board (CAIB) recommendation.

BACKGROUND

A significant amount of Orbiter wiring is insulated with Kapton, a polyimide film used as electrical insulation. Kapton-insulated wire has many advantages; however, over the years several concerns have been identified and addressed by the Space Shuttle Program (SSP) through both remedial and corrective actions.

Arc tracking, one of these ongoing concerns, was highlighted during STS-93 as a result of a short circuit in the wiring powering one of the channels of the Space Shuttle Main Engine controllers. Arc tracking is a known failure mode of Kapton wiring in which the electrical short can propagate along the wire and to adjacent wiring. Following STS-93, NASA initiated an extensive wiring investigation program to identify and repair/replace discrepant wiring. NASA also initiated a program of Critical Wire Separation efforts. This program separated redundant critical function wires that were colocated in a single wire bundle into separate wire bundles to mitigate the risk of an electrical short on one wire arc tracking to an adjacent wire and resulting in the total loss of a system. In areas where complete separation was not possible, inspections are being performed to identify discrepant wire, repair/replace it, and to protect against damage that may lead to arc tracking. In addition, abrasion protection (convoluted tubing or Teflon wrap) is being added to wire bundles that carry circuits of specific concern and/or are routed through areas of known high damage potential.

The STS-93 wiring investigation also led to improvements in the requirements for wiring inspections, wiring inspection techniques, and wire awareness training of personnel working in the vehicle. Wiring was inspected, separated, and protected in the accessible areas during the general flight-to-flight Operations and Maintenance Requirements Specification Document (OMRSD) process. The wiring that was inaccessible during the OMRSD process was inspected, separated, and protected during the Orbiter Maintenance Down Period.

Currently, visual inspection is the most effective means of detecting wire damage. Technology-assisted techniques such as Hipot, a high-potential dielectric verification test, and time domain reflectometry (TDR), a test that identifies changes in the impedance between conductors, are rarely effective for detecting damage that does not expose the conductor or where a subtle impedance change is present. Neither is an effective method for detecting subtle damage to wiring insulation. However, for some areas, visual inspection is impractical. The Orbiters contain some wire runs, such as those installed beneath the crew module, that are completely inaccessible to inspectors during routine ground processing. Even where wire is installed in accessible areas, not every wire segment is available for inspection due to bundling and routing techniques. However, the results of wire inspections, particularly since STS-93, have shown that the vast majority of wire damage is caused by maintenance workers accessing and working in areas where wire bundles are present. Areas that must be accessed for normal flight-to-flight processing, such as the payload bay or the environmental control systems bay, are particularly vulnerable.

NASA IMPLEMENTATION

NASA initially took a broad approach to mitigating Orbiter wiring concerns by evaluating promising new technologies for nondestructive evaluation (NDE) of wires, benchmarking with the practices of other government agencies, improving its visual wire inspection techniques, and creating a study group to recommend improvements to wiring issues.

NASA's initial work on NDE involved the Ames Research Center (ARC), where engineers were developing a proposed Hybrid Reflectometer, a TDR derivative, to detect defects in wiring. At the Langley Research Center (LaRC) engineers were developing a wire insulation age-life tester and an ultrasonic crimp joint tool to measure the integrity of wire crimps as they are made. At the Johnson Space Center (JSC) engineers were evaluating a destructive age-life test capability.

Prior to the articulation of the Vision for Space Exploration, NASA was particularly interested in the issue of aging wiring as a part of the Shuttle Service Life Extension Program to the year 2020 and potential 40-year service life of the Orbiters. Military and civilian aircraft are also frequently flown beyond their original design lives. NASA began an effort to benchmark with industry, academia, and other government agencies to find the most effective means to address the aging wiring concerns. Examples are NASA's participation on the Joint Council for Aging Aircraft and its collaboration with the Air Force Research Laboratory.

To improve inspection techniques, the SSP more clearly defined requirements for Category I Inspections (cutting the minimum wire ties needed to perform repair/replacement, opening up bundles, and spreading out and inspecting the additional wires made available) and Category II Inspections (inspecting bundle periphery with 10× magnification, and opening bundles if damage was noted). The Program also planned to update a previous Boeing study that evaluated types of wire insulation other than Kapton, planned to identify and map "inaccessible" wiring, and considered potential wire replacement.

Finally, the SSP assigned an action to the Orbiter Project Office to research, evaluate, and present a comprehensive list of options to address the wiring issue in general and CAIB Recommendation 4.2-2 specifically. An Orbiter Wiring Working Group composed of engineers from SSP, JSC, and Kennedy Space Center (KSC) Engineering, United Space Alliance. and Boeing began this evaluation in 2003.

STATUS

In January 2004, a new national policy for U.S. Space Exploration was established and the planned life of the Space Shuttle was shortened. Following its return to flight, the Space Shuttle will be used to complete assembly of the International Space Station, planned for the end of the decade, and then the Space Shuttle will be retired. Due to this reduced service life, NASA's approach to complying with CAIB Recommendation 4.2-2 was appropriately adjusted.

On June 17, 2004, the Orbiter Wiring Working Group presented to the PRCB a four-prong, two-phase approach to address wiring issues and respond to CAIB Recommendation 4.2-2. The four prongs or options were: (1) inspect and Protect, by continuing to improve upon current wiring inspections and activities at KSC; (2) invest in the development of NDE, including a wire insulation tester, a wire age life tester, and an ultrasonic wire crimp tool; (3) perform destructive evaluations to determine whether the Orbiter wiring does, in fact, show aging effects that are of concern; and (4) evaluate wire replacement for the Orbiters. The two phases related to NDE were Phase I – Proof of Concept and Phase II – Delivery of a Working Unit.

In light of the reduced service life of the Orbiter, the PRCB approved option 1, inspect and protect, and option 3, perform destructive evaluations. Options (2) and (4) were not approved and, as a consequence, further NDE work at the ARC and LaRC is no longer being funded by the SSP. The investment in NDE in option 2 was felt to offer little return on investment considering the relatively low technology readiness level of wiring NDE techniques. Also, few remaining flights could make use of the new NDE due to the time required to develop, test, and field operational units. In view of the planned retirement of the Space Shuttles in 2010, replacing Orbiter wiring was assessed as not cost effective.

In contrast, the inspect and protect approach continues with wiring damage corrective actions that have been in place since the post-STS-93 wiring efforts, including lessons learned to date. NASA also chartered the Orbiter Wiring Team to evaluate a wiring destructive testing program to better characterize the specific vulnerabilities of Orbiter wiring to aging and damage, and to predict future wiring damage, particularly in inaccessible areas.

To formalize wiring inspection improvements, NASA revised Specification ML0303-0014, "Installation Requirements for Electrical Wire Harnesses and Coaxial Cables," with improved guidelines for wire inspection procedures and protection protocols. A new Avionics Damage Database was implemented to capture statistical data to NASA's ability to analyze and predict wiring damage trends. NASA also initiated an aggressive wire damage awareness program that limits the number of people given access to Orbiter areas where wiring can be damaged. In addition, specific training is now given to personnel who require entry to areas that have a high potential for wiring damage. This training has already helped raise awareness and reduce unintended processing damage.

To improve our understanding of wiring issues for the remaining service life of the Space Shuttle, information and technical exchanges will continue between the SSP, NASA research centers, and other agencies dealing with aging wiring issues, such as the Federal Aviation Administration and the Department of Defense.

FORWARD WORK

In April 2005 the multi-disciplinary Orbiter Wiring Working Group will present its findings to the Orbiter Project Office regarding the need for and feasibility of a destructive age-life testing capability. The SSP will continue to evaluate the risk of aging/damaged wiring against the other major risk drivers in the Program, within the constraints of current technical capabilities, and given the Shuttle's planned retirement at the end of the decade.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Apr 04 (Completed)	Present project plan to the PRCB

Columbia Accident Investigation Board

Recommendation 4.2-1

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

Note: The Stafford-Covey Return to Flight Task Group held a plenary session on December 15, 2004, and NASA's progress toward answering this recommendation was reviewed. The Task Group agreed the actions taken were sufficient to fully close the recommendation.

BACKGROUND

The External Tank (ET) is attached to the Solid Rocket Boosters (SRBs) at the forward skirt thrust fitting by the forward separation bolt. The pyrotechnic bolt is actuated at SRB separation by fracturing the bolt in half at a predetermined groove, releasing the SRBs from the ET thrust fittings. The bolt catcher attached to the ET fitting retains the forward half of the separation bolt. The other half of the separation bolt is retained within a cavity in the forward skirt thrust post (figure 4.2-1-1).

The STS-107 bolt catcher design consisted of an aluminum dome welded to a machined aluminum base bolted to both the left- and right-hand ET fittings. The inside of the bolt catcher was filled with a honeycomb energy absorber to decelerate the ET half of the separation bolt (figure 4.2-1-2).

Static and dynamic testing demonstrated that the manufactured lot of bolt catchers that flew on STS-107 had a factor of safety of approximately 1. The factor of safety for the bolt catcher assembly should be 1.4.

NASA IMPLEMENTATION

NASA determined that the bolt catcher assembly and related hardware needed to be redesigned and qualified by testing as a complete system to demonstrate compliance with factor-of-safety requirements.

NASA completed the redesign of the bolt catcher assembly, the redesign and resizing of the ET attachment bolts and inserts, the testing to characterize the energy absorber material, and the testing to determine the design loads.

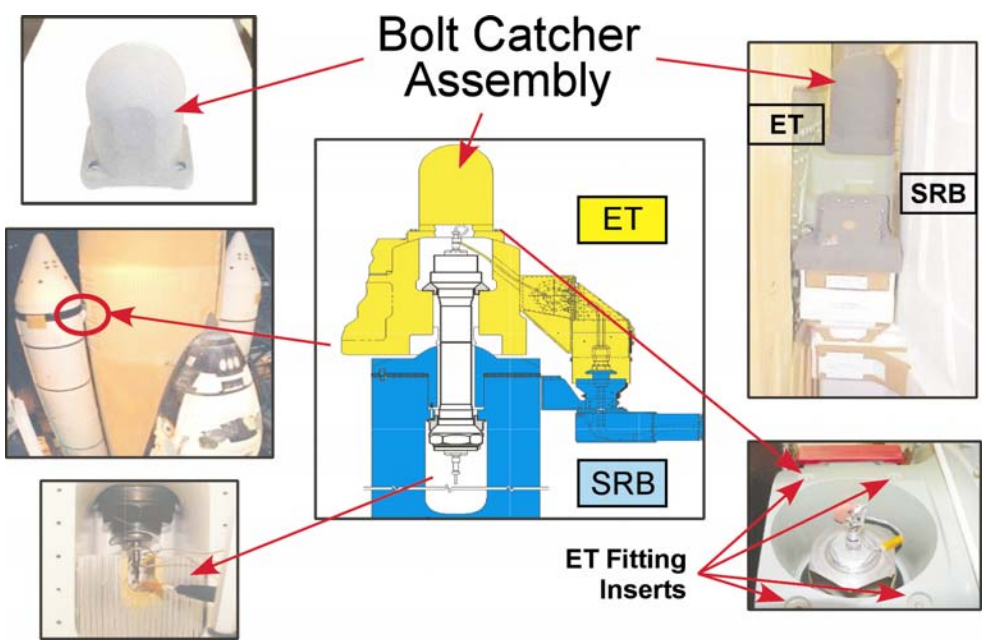


Figure 4.2-1-1. SRB/ET forward attach area.

Figure 4.2-1-2. Bolt catcher impact testing.

Figure 4.2-1-3. New one-piece forging design.

The bolt catcher housing will be fabricated from a single piece of aluminum forging (figure 4.2-1-3) that removes the weld from the original design (figure 4.2-1-4).

Further, new energy-absorbing material and thermal protection material have been selected (figure 4.2-1-4), and the ET attachment bolts and inserts (figure 4.2-1-5) have been redesigned and resized.

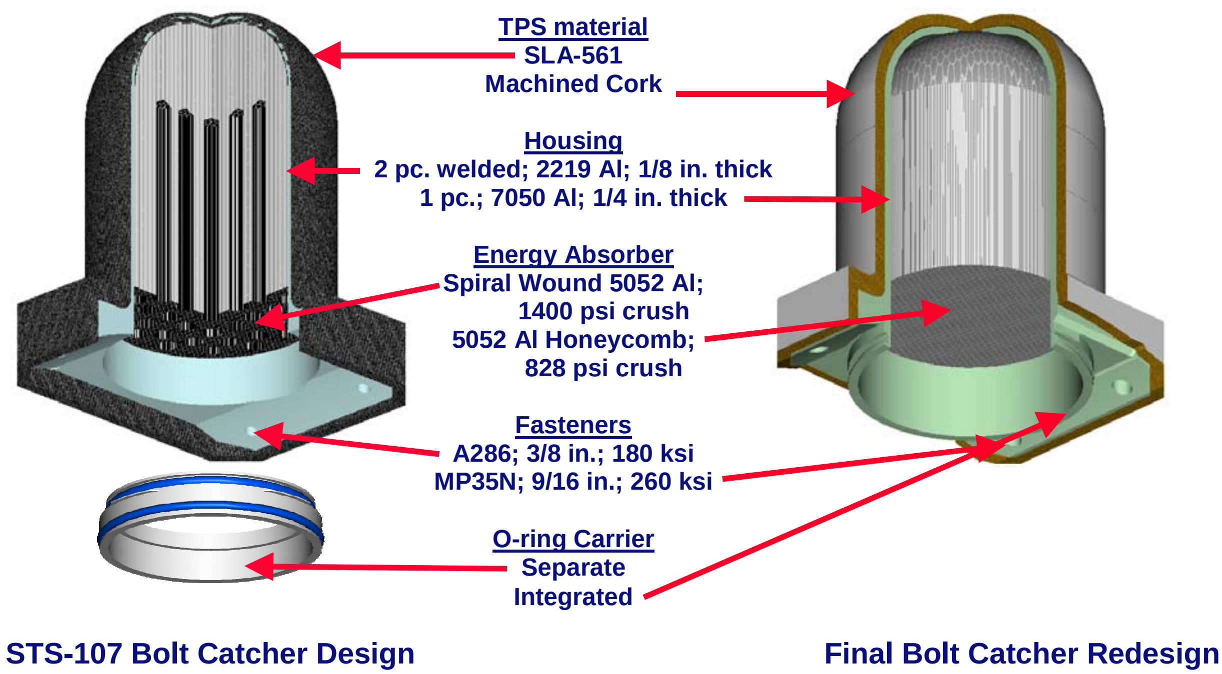


Figure 4.2-1-4. Old and new bolt catcher design comparison.

STATUS

Structural qualification to demonstrate that the assembly complies with the 1.4 factor-of-safety requirement is complete. Cork has been selected as the Thermal Protection System (TPS) material for the bolt catcher. TPS qualification testing is complete including weather exposure followed by combined environment testing, which includes vibration, acoustic, thermal, and pyrotechnic shock testing.

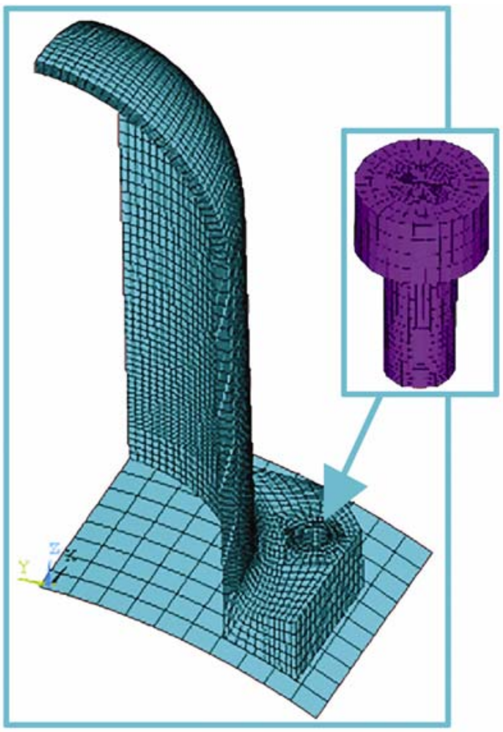


Figure 4.2-1-5. ET bolt/insert finite element model.

FORWARD WORK

None.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Space Shuttle Program (SSP)	May 04 (Completed)	Complete Critical Design Review
SSP	Oct 04 (Completed)	Complete Qualification
SSP	Feb 05 (Completed)	First Flight Article Delivered

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]

Note: The Stafford-Covey Return to Flight Task Group held a plenary session on December 15, 2004, and NASA's progress toward answering this recommendation was reviewed. The Task Group agreed the actions taken were sufficient to fully close this recommendation.

BACKGROUND

External Tank (ET) final closeouts and intertank area hand-spraying processes typically require more than one person in attendance to execute procedures. Those closeout 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 to stamp the build paper to verify their presence, and to 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.

In addition to these specific corrective measures taken by the ET Project, in March 2004 the Space Shuttle Program (SSP) widened the scope of this corrective action in response to a recommendation from the Return to Flight Task Group (RTFTG). The scope was widened to include all flight hardware projects. An audit of all final closeouts will be performed to ensure compliance with the existing guidelines that a minimum of two persons witness final flight hardware closures for flight for both quality assurance and security purposes.

The audits included participation from Project engineers, technicians, and managers. The following were used to complete the audit: comprehensive processing and manufacturing reviews, which included detailed work authorization and manufacturing document appraisals, and on-scene checks.

STATUS

The SSP has approved the revised approach for ET TPS certification, and the Space Flight Leadership Council approved it for RTFTG review. TPS verification activities are under way, and specific applicable ET processing procedures have been changed.

All major flight hardware elements (Orbiter, ET, Solid Rocket Booster, Solid Rocket Motor, extravehicular activity, vehicle processing, and main engine) have concluded their respective audits as directed by the March 2004 SSP initiative. The results of the audits were presented to the Program Manager on May 26, 2004. The two-person closeout guideline was previously well-established in the SSP and largely enforced by multiple overlapping quality assurance and safety requirements. A few projects have identified and are addressing some specific processing or manufacturing steps to extend this guideline beyond current implementation; or where rigorous satisfaction of this guideline can be better documented. Changes to Program-level requirements documents are complete, and will include the requirement for the projects and elements to have a minimum of two people witness final closeouts of major flight hardware elements.

In April 2004, the Stafford-Covey Return to Flight Task Group reviewed NASA's progress and agreed to conditionally close this recommendation. The full intent of CAIB Recommendation 4.2-3 has been met and full closure of this recommendation was achieved in December 2004.

FORWARD WORK

None.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
ET	Dec 03 (Completed)	Review revised processes with RTFTG
All flight hardware elements	May 04 (Completed)	Audit results of all SSP elements due
ET	May 04 (Completed)	Assessment of Audit Results
SSP	May 04 (Completed)	SSP element audit findings presented to SSP Manager
SSP	Jun 04 (Completed)	Responses due; PRCB action closed
SSP	Jan 05 (Completed)	Revised requirements formally documented

Columbia Accident Investigation Board

Recommendation 4.2-4

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

BACKGROUND

Micrometeoroid and orbital debris (MMOD) is a continuing concern. The current differences between the International Space Station (ISS) and Orbiter MMOD risk allowances for a critical debris impact are based on the original design specifications for each of the vehicles. Specifically, the ISS was designed for long-term MMOD exposure, whereas the Orbiter was designed for short-term MMOD exposure. The debris impact factors that are considered when determining the MMOD risks for a spacecraft are mission duration, attitude(s), altitude, inclination, year, and the on-board payloads.

The current Orbiter impact damage guidelines dictate that there will be no more than a 1 in 200 risk for loss of vehicle for any single mission. This recommendation suggests that the Orbiter meet the same degree of safety that the ISS meets in regards to MMOD risks. The ISS currently has a 0.5 percent catastrophic risk of MMOD debris impact per year. If we assume there will be five Space Shuttle flights per year, this would require that the Orbiter meet an annual average MMOD critical damage risk of 1 in 1000 for any single mission. This risk tolerance may vary from mission to mission, depending on whether the risk profile is determined annually or over the remaining life of the Shuttle Program. NASA continues to evaluate the appropriate means of determining the Shuttle MMOD risk profile.

NASA uses a computer simulation and modeling tool called BUMPER to assess the risk from MMOD impact to the Orbiter during each flight and takes into account the mission duration, attitude variations, altitude, and other factors. BUMPER has been certified for use on both the ISS and the Orbiter. BUMPER has also been examined during numerous technical reviews and deemed to be the world standard for orbital debris risk assessment. Optimized trajectories, vehicle changes, results from trade studies, and more detailed ballistic limit calculations are used to improve the fidelity of the BUMPER results.

NASA IMPLEMENTATION

To comply with the recommendation to operate the Orbiter with the same degree of safety for MMOD as calculated for ISS, NASA will continue to evaluate the following options for possible implementation in the long term:

- Orbiter vehicle design upgrades to decrease vulnerability to MMOD
- Operational changes during the docked mission phase
- Development of an inspection capability to detect and repair critical damage
- Addition of an on-board impact sensor system to detect critical damage that may occur to the Thermal Protection System (TPS) during ascent or while on orbit.

Once they are fully defined by the Space Shuttle Program (SSP), NASA will change the MMOD safety criteria from guidelines to requirements.

STATUS

The SSP's ability to implement the wide range of mitigations necessary to comply with this recommendation is limited by the time that the Shuttle will continue to operate before retirement after completion of ISS assembly at the end of the decade. Given this limitation, it is unlikely that NASA can achieve the Space Station's level of risk (1 in 1000). NASA's assessments indicate that an alternate operational docked attitude change may decrease the Orbiter's MMOD risk from 1 in 200 to approximately 1 in 485. Currently, NASA is performing an Orbiter wing leading edge (WLE) damage assessment to determine impact damage locations on the Reinforced Carbon-Carbon (RCC) surfaces that can be safely tolerated during entry and landing. An MMOD risk sensitivity to the RCC WLE failure criteria indicates that a more conservative failure criteria change will limit NASA's ability to achieve the 1 in 485 risk. Appropriate changes will be made over time according to prioritization based on a combination of the efficacy of the change and the relative difficulty of its implementation.

In the short term following return to flight, NASA is considering the following actions to reduce critical risk:

1. Alternate operational docked attitude, yawing the ISS-Shuttle stack by 180 degrees
2. Implementing late mission inspection of TPS, followed by repair if necessary
3. Installing WLE damage detection sensors and implementing inspection, repair, and/or contingency Shuttle Crew Support (CSCS) operations, if damage is detected during flight.

A longer-term strategy that shows promise of achieving a reduction in MMOD risk is also under consideration. This strategy includes the following:

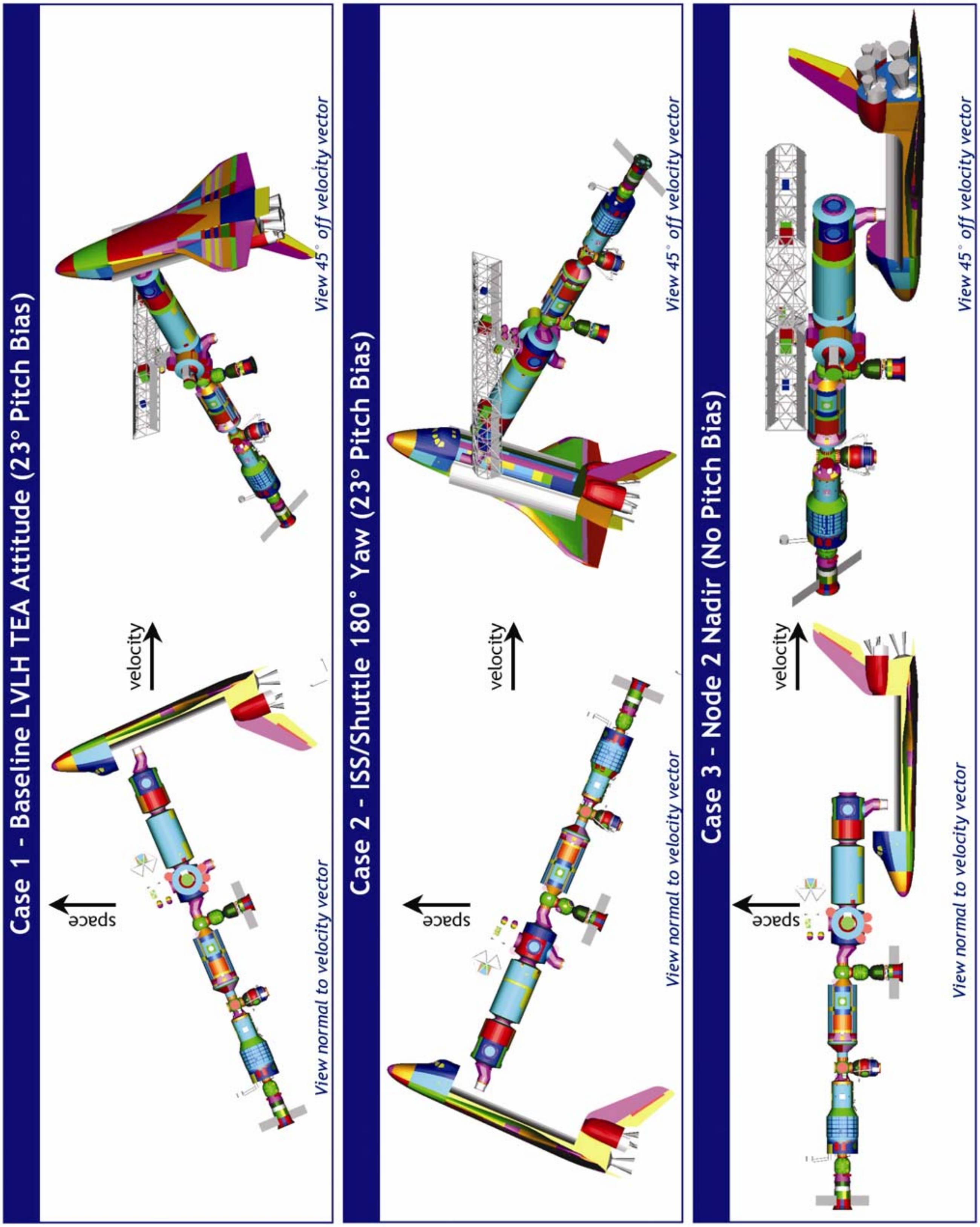
1. Continuing the 180-degree yaw strategy post-ISS dock
2. Selective hardening of TPS tiles and WLE to reduce impact hazards from both launch debris and on-orbit MMOD strikes
3. Extending the impact detection sensors to the wing and belly TPS areas of the vehicle. If damage is detected, closer inspection of the impacted area will be initiated, followed by repair or resorting to CSCS procedures if necessary

FORWARD WORK

Investigations will continue on potential vehicle modifications, such as new impact debris sensors, next-generation tiles and toughened strain isolation pad materials, improved RCC, and improved crew module aft bulkhead protection. Additionally, further work will focus on assessing Orbiter WLE and nose cap RCC, radiator, and windows MMOD risk trades associated with yawing the ISS-Shuttle stack, post docking, by 180 degrees (i.e., change in Orbiter MMOD risk damage potential). Upon completion of the WLE damage assessment, NASA will update the new RCC loss of vehicle failure criteria for calculating Orbiter MMOD critical damage risk. NASA will also evaluate the cost/benefits for late inspection of RCC and other TPS for critical MMOD impact damage. Although WLE impact detection hardware has been installed, its capability for detecting MMOD damage is limited due to short-term battery life (sensors will be active 3–5 hours mission elapsed time). An SSP decision to upgrade power has been made, but flight effectivity for the power upgrade is yet to be determined. The benefit for the WLE sensors in reducing loss of communications risk from MMOD impact will be included in the risk assessments after the WLE sensors have been proven in the first two flights and power upgrades have been implemented. Hypervelocity impact tests will continue to be performed, and the BUMPER code will be updated to support the risk reduction effort.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Dec 03 (Completed)	Assess adequacy of MMOD requirements
SSP	Apr 04 (Completed)	WLE Sensor System Critical Design Review
SSP	Nov 04 (Completed)	WLE Impact Detection System hardware delivery (OV-103)
SSP	Mar 05 (in work)	Assess WLE RCC impact damage tolerance
SSP	Mar 05 (in work for STS-114)	Flight-by-flight SSP review of forward work status and MMOD requirements


Case 1 - Baseline LVLH TEA Attitude (23° Pitch Bias)
space
velocity
View normal to velocity vector
View 45° off velocity vector
Case 2 - ISS/Shuttle 180° Yaw (23° Pitch Bias)
space
velocity
View normal to velocity vector
View 45° off velocity vector
Case 3 - Node 2 Nadir (No Pitch Bias)
space
velocity
View normal to velocity vector
View 45° off velocity vector

Columbia Accident Investigation Board

Recommendation 4.2-5

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

Note: The Stafford-Covey Return to Flight Task Group held a plenary session on December 15, 2004, and NASA’s progress toward answering this recommendation was revuewed. The Task Group agreed the actions taken were sufficient to fully close this recommendation.

BACKGROUND

Beginning in 2001, debris at Kennedy Space Center (KSC) was divided into two categories, “processing debris” and foreign object debris (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 and United Space Alliance (USA) have changed work procedures to consider all debris equally important and preventable. Rigorous definitions of FOD that are the industry standard have been adopted. These new definitions adopted from National Aerospace FOD Prevention, Inc. guidelines and industry standards include Foreign Object Debris (FOD), Foreign Object Damage, and Clean-As-You-Go. FOD is redefined as “a substance, debris or article alien to a vehicle or system which would potentially cause damage.”

KSC chartered a multidiscipline NASA/USA team to respond to this recommendation. Team members were selected for their experience in important FOD-related disciplines including processing, quality, and corrective engineering; process analysis and integration; and operations management. The team began by fact-finding and benchmarking to better understand the industry standards and best practices for FOD prevention. They visited the Northrup Grumman facility at Lake Charles, La.; Boeing Aerospace at Kelly Air Force Base, Texas; Gulfstream Aerospace in Savannah, Ga.; and the Air Force’s Air Logistics Center in Oklahoma City, Okla. At each site, the team studied the FOD prevention processes, documentation programs, and assurance practices.

Armed with this information, the NASA/USA team developed a more robust FOD prevention program that not only fully answered the *Columbia* Accident Investigation Board (CAIB) recommendation, but also raised the bar by instituting a myriad of additional improvements. The new FOD program is anchored in three fundamental areas of emphasis: First, it eliminates various categories of FOD, including “processing debris,” and treats all FOD as preventable and with equal importance. Second, it re-emphasizes the responsibility and authority for FOD prevention at the operations level. FOD prevention and elimination are stressed and the work force is encouraged to report any and all FOD found by entering the data in the FOD database. This activity is performed with the knowledge that finding and reporting FOD is the goal of the Program and employees will not be penalized for their findings. Third, it elevates the importance of comprehensive independent monitoring by both contractors and the Government.

USA has also developed and implemented new work practices and strengthened existing practices. This new rigor will reduce the possibility for temporary worksite items or debris to migrate to an out-of-sight or inaccessible area, and it serves an important psychological purpose in eliminating visible breaches in FOD prevention discipline.

FOD “walkdowns” have been a standard industry and KSC procedure for many years. These are dedicated periods during which all employees execute a prescribed search pattern throughout the work areas, picking up all debris. USA has increased the frequency and participation in walkdowns, and has also increased the number of areas that are regularly subject to them. USA has also improved walkdown effectiveness by segmenting FOD walkdown areas into zones. Red zones are all areas within three feet of flight hardware and all areas inside or immediately above or below flight hardware. Yellow zones are all areas within a designated flight hardware operational processing area. Blue zones are desk space and other administrative areas within designated flight hardware operational processing areas.

Additionally, both NASA and USA have increased their independent monitoring of the FOD prevention program. The USA Process Assurance Engineering organization randomly audits work areas for compliance with such work rules as removal of potential FOD items before entering work areas and tethering of those items that cannot be removed (e.g., glasses), tool control protocol, parts protection, and Clean-As-You-Go housekeeping procedures. NASA Quality personnel periodically participate in FOD walkdowns to assess their effectiveness and oversee contractor accomplishment of all FOD program requirements.

An important aspect of the FOD prevention program has been the planning and success of its rollout. USA assigned FOD Point of Contact duties to a senior employee who led the development of the training program from the very beginning of plan construction. This program included a rollout briefing followed by mandatory participation in a new FOD Prevention Program Course, distribution of an FOD awareness booklet, and hands-on training on a new FOD tracking database. Annual FOD Prevention training is required for all personnel with permanent access permissions to controlled Shuttle processing facilities at KSC. This is enforced through the KSC Personnel Access Security System. Another important piece of the rollout strategy was the strong support of senior NASA and USA management for the new FOD program and their insistence upon its comprehensive implementation. Managers at all levels will take the FOD courses and periodically participate in FOD walkdowns.

The new FOD program has a meaningful set of metrics to measure effectiveness and to guide improvements. FOD walkdown findings will be tracked in the Integrated Quality Support Database. This database will also track FOD found during closeouts, launch countdowns, postlaunch pad turnarounds, landing operations, and NASA quality assurance audits. “Stumble-on” FOD findings will also be tracked, as they offer an important metric of program effectiveness independent of planned FOD program activities. For all metrics, the types of FOD and their locations will be recorded and analyzed for trends to identify particular areas for improvement. Monthly metrics reporting to management will highlight the top five FOD types, locations, and observed workforce behaviors, along with the prior months’ trends. Continual improvement will be a hallmark of the revitalized FOD program.

STATUS

NASA and USA completed the initial benchmarking exercises, identified best practices, modified operating plans and database procedures, and conducted the rollout orientation and initial employee training. Official, full-up implementation began on July 1, 2004, although many aspects of the plan existed in the previous FOD prevention program in place at KSC. Assessment audits by NASA and USA were conducted beginning in October 2004. Corrective Action Plans have been established to address the findings and observations identified during the two audits. Schedules for the verification of the actions taken and for verifying the effectiveness of the corrective actions have been established to ensure the ongoing effectiveness of the FOD prevention program. Continual improvement will be vigorously pursued for the remainder of the life of the Shuttle. In July 2004, the Stafford-Covey Return to Flight Task Group reviewed NASA’s progress and agreed to conditionally close this recommendation. The full intent of CAIB Recommendation 4.2-5 has been met and full closure of this recommendation was achieved in December 2004. NASA and USA have gone beyond the recommendation to implement a truly world-class FOD prevention program.

FORWARD WORK

None.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Space Shuttle Program (SSP)	Ongoing	Review and trend metrics
SSP	Oct 03 (Completed)	Initiate NASA Management walkdowns
SSP	Dec 03 (Completed)	FOD Control Program benchmarking
SSP	Jan 04 (Completed)	Revised FOD definition
SSP	Apr 04 (Completed)	Draft USA Operating Procedure released for review
SSP	Jul 04 (Completed)	Implement FOD surveillance
SSP	Oct 04 (Completed)	Baseline audit of implementation of FOD definition, training, and surveillance
SSP	Ongoing	Periodic surveillance audit

Columbia Accident Investigation Board

Recommendation 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]

BACKGROUND

The Mission Management Team (MMT) is responsible for making Space Shuttle Program (SSP) decisions regarding preflight and in-flight activities and operations that exceed the authority of the launch director or the flight director. The MMT's responsibilities for a specific Space Shuttle mission start with the first scheduled meeting two days prior to a scheduled launch (L-2). Kennedy Space Center prelaunch activities continue through launch and terminate at a mission elapsed time of two hours. At that time, MMT activities transfer to the Johnson Space Center. The flight MMT meets daily during the subsequent on-orbit, entry, landing phases and terminates with crew egress from the vehicle. When the flight MMT is not in session, all MMT members are on-call and required to support emergency MMTs convened because of anomalies or changing flight conditions.

MMT training, including briefings and simulations, has previously concentrated on the prelaunch and launch phases, including launch aborts.

NASA IMPLEMENTATION

NASA's response will be implemented in two steps: (1) to review and revise MMT processes and procedures; and (2) to develop and implement a training program consistent with those process revisions.

NASA determined through an in-depth review of the processes and functions of STS-107 and previous flight MMTs that additional rigor and discipline are required in the flight MMT process. An essential piece of strengthening the MMT process is ensuring all safety, engineering, and operations concerns are heard and dispositioned appropriately. NASA is expanding the processes for the review and dispositioning of on-orbit anomalies and issues. The flight MMT meeting frequency and the process for requesting an emergency MMT meeting have been more clearly defined. NASA will enforce the requirement to conduct daily MMT meetings.

NASA has established a formal MMT training program comprised of a variety of training activities and MMT simulations. MMT simulations will bring together the flight crew, flight control team, launch control team, engineering staff, outside agencies, and MMT members to improve communication and teach better problem-recognition and reaction skills. MMT members, except those serving exclusively in an advisory capacity or in a Department of Defense Mission Support position, are required to complete a minimum set of training requirements to attain initial certification prior to performing MMT responsibilities, and participate in a sustained training program to maintain certification. The SSP is maintaining training records to ensure compliance with the new requirements. NASA has employed independent external consultants to assist in developing these training activities and to evaluate overall training effectiveness.

The SSP reviewed the MMT processes and revised the Program documentation (NSTS 07700, Volume VIII, Operations, Appendix D) to implement the following significant changes:

1. Membership, organization, and chairmanship of the preflight and in-flight MMT will be standardized. The SSP Deputy Manager will chair both phases of the MMT.
2. Flight MMT meetings will be formalized through the use of standardized agenda formats, presentations, action item assignments, and a readiness poll. Existing SSP meeting support infrastructure will be used to ensure MMT meeting information is distributed as early as possible before scheduled meetings, as well as timely generation and distribution of minutes subsequent to the meetings.
3. Responsibilities for the specific MMT members have been defined. MMT membership will be expanded and will be augmented with advisory members from the Safety and Mission Assurance (S&MA), Independent Technical Authority, NASA Engineering and Safety Center, and engineering and Program management disciplines. MMT membership for each mission is established by each participating

organization in writing prior to the first preflight MMT.

4. Each MMT member will define internal processes for MMT support and problem reporting.

5. Formal processes will be established for review of findings from ascent and on-orbit imagery analyses, postlaunch hardware inspections, and ascent reconstruction and any other flight data reviews to ensure a timely, positive reporting path for these activities.

6. A process will be established to review and disposition mission anomalies and issues. All anomalies will be identified to the flight MMT. The Space Shuttle Systems Engineering and Integration Office will maintain and provide a status of an integrated anomaly list at each MMT. For those items deemed significant by any MMT member, a formal flight MMT action and office of primary responsibility (OPR) will be assigned and an independent risk assessment will be provided by S&MA. The OPR will provide a status of the action at all subsequent flight MMT meetings. The MMT will require written requests for action closure. The request must include a description of the issue (observation and potential consequences), analysis details (including employed models and methodologies), recommended actions and associated mission impacts, and flight closure rationale, if applicable.

7. NASA has refurbished the MMT Command Center to provide increased capacity and other improvements for the MMT. Improvements include a video teleconferencing capability, a multi-user collaboration tool, and a larger room to allow more subject matter experts and MMT members. The MMT Command Center is operational. The first simulation was held in the new MMT Command Center in November 2004.

NASA has also completed a Mission Evaluation Room console handbook that includes MMT reporting requirements, a flight MMT reporting process for on-orbit vehicle inspection findings, and MMT meeting support procedures. Additionally, the SSP published a formal MMT training plan (NSTS 07700, Volume II, Program Structure and Responsibilities, Book 2 - Space Shuttle Program Directives, Space Shuttle Program Directive 150) that defines the generic training requirements for MMT certification. This plan is comprised of three basic types of training: courses and workshops, MMT simulations, and self-instruction. Courses, workshops, and self-instruction materials were selected to strengthen individual expertise in human factors, critical decision making, and risk management of high-reliability systems.

STATUS

Additionally, the SSP published a training calendar for fiscal years 2004 and 2005 that identifies the specific training activities to be conducted and, for each activity, the associated date, objective, location, and point of contact. MMT training activities are well under way with several courses/workshops held at various NASA centers and 12 simulations completed.

FORWARD WORK

Revisions to project and element processes will be established consistent with the new MMT requirements and will follow formal Program approval. Associated project and element activities in development include but are not limited to a flight MMT reporting process for launch imagery analysis and on-orbit vehicle inspection findings.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Oct 03 (Completed)	MMT Interim training plan
SSP	Oct 03 (Completed)	MMT process changes to Program Requirements Change Board
SSP	Oct 03 (Completed)	Project/element process changes
SSP	Nov 03 – Return to Flight	MMT training
SSP		MMT Simulation Summary
	Nov 03 (Completed)	MMT On-Orbit simulation
	Dec 03 (Completed)	MMT SSP/International Space Station (ISS) Joint On-Orbit simulation
	Feb 04 (Completed)	MMT On-Orbit simulation
	Apr 04 (Completed)	MMT Prelaunch simulation
	May 04 (Completed)	MMT On-Orbit simulation involving Thermal Protection System (TPS) inspection
	Jun 04 (Completed)	MMT Prelaunch simulation
	Jul 04 (Completed)	MMT On-Orbit simulation
	Sep 04 (Completed)	MMT On-Orbit simulation
	Nov 04 (Completed)	MMT SSP/ISS Joint On-Orbit simulation involving TPS inspection
	Dec 04 (Completed)	MMT Prelaunch simulation
	Jan 05 (Completed)	MMT Prelaunch Contingency simulation
	Feb 05 (Completed)	MMT Prelaunch/On-Orbit/Entry Integrated simulation involving TPS inspection
SSP	Dec 03 (Completed)	Status to Space Flight Leadership Council and Stafford/Covey Task Group
SSP	Feb 04 (Completed)	MMT final training plan
SSP	Apr 04 (Completed)	Status to Stafford/Covey Task Group
SSP	Aug 04 (Completed)	Miscellaneous MMT process and training revisions to address simulations lessons learned

Responsibility	Due Date	Activity/Deliverable
SSP	Sep 04 (Completed)	Status to Stafford/Covey Return to Flight Task Group
SSP	Nov 04 (Completed)	Complete refurbishment of MMT Command Center
SSP	Feb 05 (Completed)	Update MMT Training Plan

Columbia Accident Investigation Board

Recommendations 9.1-1, 7.5-1, 7.5-2, and 7.5-3

R9.1-1 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]

R7.5-1 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 sub-system, 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
- Approves the provisions of the recertification program called for in Recommendation [R9.2-1]

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

R7.5-2 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.

R7.5-3 Reorganize the Space Shuttle Integration Office to make it capable of integrating all elements of the Space Shuttle Program, including the Orbiter.

INTRODUCTION

NASA, under the leadership of the Office of Safety and Mission Assurance (OSMA) and the Office of the Chief Engineer, is implementing a plan addressing the Agency-wide response to Recommendation 9.1-1 – referred to as the "9.1-1 Plan" and titled "NASA's Plan for Implementing Safe and Reliable Operations." Although the *Columbia* Accident Investigation Board (CAIB) only recommended that NASA prepare a detailed plan for 9.1-1 prior to Return to Flight (RTF), NASA has begun the transformation called for in the three relevant Chapter 7 recommendations.

The CAIB's independent investigation revealed areas in NASA's organization and its operations that needed substantial improvement before returning the Space Shuttle to safe and reliable flight operations. This report addresses three fundamental changes that NASA is making to improve the safety and reliability of its operations:

- Restore specific engineering technical authority, independent of programmatic decision-making.
- Increase the authority, independence, and capability of the Agency Safety and Mission Assurance (SMA) organizations.
- Expand the role of the Space Shuttle Integration Office to address the entire Space Shuttle system.

These changes reflect careful and diligent review of the CAIB's investigation as a basis for implementation of their recommendations. Specifically, these changes address CAIB Recommendations R9.1-1 and its accompanying Recommendations R7.5-1, R7.5-2, and R7.5-3.

As a first necessary step to put the CAIB's recommendations regarding independent technical authority into practice, the NASA Administrator designated the Chief Engineer as the NASA Technical Authority (TA). The Chief Safety and Mission Assurance Officer provides leadership, policy direction, functional oversight, assessment, and coordination for the safety and quality assurance disciplines across the Agency. The role of the Shuttle Integration Office (now the Shuttle Systems Engineering and Integration Office) has been strengthened so that it integrates all of the elements of the Space Shuttle Program (SSP). These three organizational changes—an independent technical authority, a separate and distinct independent SMA, and a focused Program management structure—form a foundation for ensuring safe and reliable operations for NASA's Space Shuttle and other missions.

Section I of this report, the first change, was issued in November 2004 to provide NASA's plan to restore specific engineering technical authority, independent of programmatic decision-making, in all of NASA's missions. Section 4.5 provides NASA's progress on implementing technical authority. Section II describes the role of SMA and how the second change increases the authority, capability, and independence of the SMA community. Section III addresses how the third change expands the role of the new Space Shuttle Systems Engineering and Integration Office to address the entire Space Shuttle system. Section 4.3 addresses the relationship of the roles and responsibilities of the ITA and SMA organizations.

NASA IMPLEMENTATION

Independent Technical Authority (R7.5-1)

This plan answers the CAIB Recommendation 7.5-1 by aggressively implementing an independent technical authority at NASA that has the responsibility, authority, and accountability to establish, monitor, and approve technical requirements, processes, products, and policy.

Technical Authority

The NASA Chief Engineer, as the TA, governs and is accountable for technical decisions that affect safe and reliable operations and is using a warrant system to further delegate this technical authority. The TA provides technical decisions for safe and reliable operations in support of mission development activities and programs and projects that pose minimum reasonable risk to humans; i.e., astronauts, the NASA workforce, and the public. Sound technical requirements necessary for safe and reliable operations will not be compromised by programmatic constraints, including cost and schedule.

As the NASA TA, the NASA Chief Engineer is working to develop a technical conscience throughout the engineering community, that is, the personal responsibility to provide safe technical products coupled with an awareness of the avenues available to raise and resolve technical concerns. Technical authority and technical conscience represent a renewed culture in NASA governing and upholding sound technical decision-making by personnel who are independent of programmatic processes. This change affects how technical requirements are established and maintained as well as how technical decisions are made, safety considerations being first and foremost in technical decision-making.

Five key principles govern the independent technical authority. This authority:

1. Resides in an individual, not an organization;
2. Is clear and unambiguous regarding authority, responsibility, and accountability;
3. Is independent of Program Management;
4. Is executed using credible personnel, technical requirements, and decision-making tools; and
5. Makes and influences technical decisions through prestige, visibility, and the strength of technical requirements and evaluations.

Warrant System

The Chief Engineer has put technical authority into practice through a system of governing warrants issued to individuals. These Technical Warrant Holders (TWHs) are proven subject matter experts with mature judgment who are operating with a technical authority budget that is independent from Program budgets and Program authority. This technical authority budget covers the cost of the TWHs and their agents as they execute their responsibility for establishing and maintaining technical requirements, reviewing technical products, and preparing and administering technical processes and policies for disciplines and systems under their purview.

The warrant system provides a disciplined formal procedure that is standardized across the Agency, and a process that is recognized inside and outside NASA in the execution of independent technical authority.

Technical Conscience

Technical conscience is personal ownership of the technical product by the individual who is responsible for that product. Committee reviews, supervisory initials, etc., do not relieve these individuals of their obligation for a safe and reliable mission operation if their technical requirements are followed. Technical conscience is also the personal principle for individuals to raise concerns regarding situations that do not "sit right" with NASA's mandate for safe and reliable systems and operations. With adoption of technical authority and the warrant system, technical personnel have the means to address and adjudicate technical concerns according to the requirements of the situation. TA and the TWHs provide the means for independent evaluation and adjudication of any concern raised in exercising technical conscience.

On November 23, 2004, the NASA Administrator issued the policy and requirements to implement technical authority through a technical warrant process. This policy was issued under NPD 1240.4 NASA Technical Authority (draft) and NPR 1240.1 Technical Warrant System (draft), and is in accordance with the plan. In December, NASA Chief Engineer Rex Geveden assigned Walter Hussey as Director of ITA Implementation to focus the Agency's internal efforts on this cultural transformation. The Chief Engineer has identified and selected TWHs and issued warrants for 26 critical areas, including all major systems for the Space Shuttle. After their selection and training, these newly assigned TWHs are now executing the responsibilities of their warrants. The Space Shuttle TWHs are making the technical decisions necessary for safe and reliable operations and are involved in RTF activities for the Space Shuttle. NASA is selecting additional TWHs to span the full range of technical disciplines and systems needed across the Agency. The Chief Engineer plans to issue several new warrants in March 2005, including one for Systems Safety Engineering who will help revitalize the conduct of safety analyses (failure mode and effects analysis (FMEA), hazards analysis, reliability engineering, etc.) as part of design and engineering.

Independent Safety (R7.5-2)

This plan answers the CAIB Recommendation 7.5-2 by aggressively addressing the fundamental problems brought out by the CAIB in three categories: authority, independence, and capability.

SMA Authority

To address the authority issue raised by the CAIB, NASA has strengthened OSMA's traditional policy oversight over NASA programs and Center line organizations with the explicit authority of the Administrator through the Deputy Administrator/Chief Operating Officer (COO) to enforce those policies. The Chief Safety and Mission Assurance Officer provides leadership, policy direction, functional oversight, assessment, and coordination for the safety, quality, and mission assurance disciplines across the Agency. Operational responsibility for the requirements of these disciplines rests with the Agency's program and line organizations as an integral part of the NASA mission. To increase OSMA's "line authority" over field SMA activities, NASA has taken four important steps:

1. The Chief Safety and Mission Assurance Officer now has explicit authority over selection, relief, and performance evaluation of all Center SMA Directors as well as the lead SMA managers for major programs, including Space Shuttle and International Space Station (ISS), as well as the Director of the Independent Verification and Validation (IV&V) Center.
2. The Chief, OSMA will provide a formal "functional performance evaluation" for each Center Director to their Headquarters Center Executive (HCE) each year.
3. "Suspension" authority is delegated to the Center Directors and their SMA Directors. This authority applies to any program, project, or operation conducted at the center or under that center's SMA oversight regardless of whether the center also has programmatic responsibility for that activity.
4. The SMA community, through their institutional chain of command up to the COO, now has the authority to decide the level of SMA support for the project/program.

NASA SMA support for the SSP consists of dedicated Program office staff, technical support from the Centers, and functional oversight from the Headquarters OSMA. A senior SMA professional heads the Program's SMA Office as the Space Shuttle SMA Manager. The SMA Manager reports directly to the Program Manager and is responsible for execution of the safety and quality assurance requirements within the Program. The Program SMA Office integrates the safety and quality assurance activities performed by all Space Operations Centers for the various projects and Program elements located at those Centers.

The Center SMA Directorates provide technical support to the Program's SMA Manager. They also provide independent safety and quality assurance functions in the form of independent assessments, safety, and reliability panel reviews. Finally, they provide a cadre of personnel dedicated to OSMA's Independent Assessment of compliance function.

SMA Independence

The CAIB recommendation requires that the OSMA be independently funded. After the Rogers Commission Report, NASA created the Office of Safety, Reliability and Quality Assurance, later renamed OSMA, and specifically set up its reporting and funding to be separate from that of the Chief Engineer's office and any of the Program Enterprises. At the time of *Columbia*, all funding for OSMA was in the corporate General and Administrative (G&A) line, separate from all other program, institutional, and mission support and functional support office funding. As for personnel, all permanent OSMA personnel are dedicated to OSMA and, therefore, are independent of program or other mission support and functional support offices. This plan retains that independent reporting and funding approach consistent with the CAIB recommendation.

With respect to Center-based civil servants and their support contractors performing safety, reliability, and quality assurance tasks, this plan calls for significant change. This plan establishes that the institution, not the program, decides SMA resource levels. Under the oversight of the Headquarters HCEs, Centers will set up SMA-"directed" service pools to allow SMA labor to be applied to programs and projects in the areas and at the levels deemed necessary by the SMA Directors and their institutional chain of authority. SMA will pre-coordinate the use of their resources with the programs to foster understanding of how SMA labor will be used. This approach will guarantee both organizational and funding independence from the programs in a way that fully addresses the CAIB's findings. Finally, the Headquarters OSMA will, for the first time, be a voting member of the Institutional Committee wherein institutional (including SMA service pool) budget decisions are made for the Agency. To aid OSMA in its resource oversight and approval responsibilities, each center SMA Directorate will develop an Annual Operating Agreement that calls out all SMA activities at the center, industrial, program support, and independent assessment.

Under NASA's old definition of independence, which focused on organizational independence, the SSP Program and Project Managers had funding approval authority for about 99% (based on fiscal year (FY) 03 estimates) of the total SMA funding level for Shuttle (includes all contractor and Center NASA and support contractor SMA resources). The remaining 1% consisted of Center SMA supervisor time (paid by Center General and Administrative funds) and approximately $2M per year of Space Shuttle Independent Assessment (IA) activity (paid for by OSMA). Under NASA's new definition of independence, which now includes the directed service pool, the SSP has funding approval authority for only about 70% of the total SMA funding level. This funding pays for Shuttle prime and sub-contractor SMA and for the small civil service SMA Management Office in the Program. The remaining funding approval is accomplished through the directed service pool. This accounts for all Center SMA Civil Service (CS), all SMA support contractors, and OSMA's IV&V and IA that supports Space Shuttle.

SMA Capability

To address SMA capability, all of the Centers have reviewed their SMA skills and resources for adequacy and added positions as required. In particular, the Space Operations Centers have all addressed staffing deficiencies as part of Shuttle RTF, and they have already begun hiring to fill vacancies. Headquarters OSMA has increased significantly its ability to provide functional oversight of all NASA SMA programs. Staffing has been increased in the Headquarters office from 48 to 51 people, partly to accommodate increased liaison needs created by addition of NASA Engineering and Safety Center (NESC), IV&V, and new assurance programs. At the time of *Columbia*, OSMA had a budget of $6M per year for IA, its primary corporate assurance tool. OSMA will continue to send IA funding to the Space Flight Centers for use by SMA Directorates in performing Center audits and supporting OSMA audits and assessment of resident programs. It also encourages the IA teams to focus more on process and functional audits than they have in the past. This plan shows a substantial increase in OSMA capability by the addition of the responsibility and budgets for the Agency software IV&V services.

The NESC, as a technical resource available to the SMA community, in coordination with the ITA, combined with IV&V and IA capabilities, provides an unprecedented increase in the independent assessment, audit, and review capability and will reinforce the SMA community's role in providing verification and assurance of compliance with technical requirements owned by the ITA, and in technical support for mishap investigations.

The ITA will own all technical requirements, including safety and reliability design and engineering standards and requirements. OSMA will continue to develop and improve generic safety, reliability, and quality (SRQ) process standards, including FMEA, risk, and hazards analysis processes; however, the ITA will specify and approve these analyses and their application in engineering technical products. OSMA's involvement with SRQ process standards will enable the Headquarters office and Center SMA organizations to better oversee compliance with safety, reliability, and quality requirements. In addition, OSMA, with the lessons learned in recent U.S. Navy (and other) benchmarking activities, will improve its functional audit capabilities, borrowing techniques used by the Naval Sea Systems Command in submarine certifications. NASA is also improving its trend analysis, problem tracking, and lessons learned systems (ref: F7.4-9, -10, and -11), all in a concerted effort to ensure the TA invokes the correct technical requirements. In order to improve OSMA insight and to reduce confusion cited in F7.4-13, NASA is formalizing its SMA Prelaunch Assessment Review (PAR) process for Shuttle and ISS, and the equivalent processes for expendable launch vehicles and experimental aerospace vehicle flight approvals, called Independent Mission Assurance Reviews (IMARs). Both of these processes will be standardized into a new NASA-wide review process called SMA Readiness Reviews (SMARRs)

In addressing the CAIB concern about the lack of mainstreaming and visibility of the system safety discipline (F7.4-4), OSMA has taken two actions, one long term and the other completed. First, as regards lack of mainstreaming of system safety engineering, the OSMA audit plan will include an assessment of the adequacy of system safety engineering by the audited project and/or line engineering organizations per the new NASA policy directives for Program management and ITA. As for the second concern about the lack of system safety visibility, for some years, the senior system safety expert in the Agency was also the OSMA Requirements Division Chief (now Deputy Chief, OSMA). To respond to the CAIB concern, OSMA has brought on a full-time experienced system safety manager who is the Agency's dedicated senior system safety assurance policy expert. In addition the Chief Engineer will select a Systems Safety Engineering Technical Warrant Holder who will be responsible for establishing systems safety engineering requirements.

The SMA Directorates supporting SSP are staffed with a combination of civil service and support contractors providing system safety, reliability, and quality expertise and services. Their role is predominantly assurance in nature, providing the Program with functional oversight of the compliance of the prime and sub-contractor engineering and operations with requirements. The civil service personnel assigned to work on Shuttle are functionally tied to their Center SMA organizations, and although some are collocated with their project or contractor element, their official supervisors are in the SMA organization.

The System Safety Review Panel (SSRP) process continues to evolve as the relationship between the ITA, SMA, and the SSP is defined and understood. This plan redefines the SSRP as the Engineering Risk Review Panels (ERRP). The ERRP is designed to improve engagement by the engineering community into the safety process, including the development and maintenance of documentation such as hazard reports.

The organizational structure of the ERRP will consist of Level 2 (Program) and Level 3 (Project/Element) functionality. The ERRP's structure and processes continue to evolve in a phased approach. Until RTF, the ITA Shuttle System TWH will be represented at all ERRP levels through Engineering trusted agents who are assigned to support each ERRP. The trusted agents ensure that the engineering interests of the ITA are represented at all working levels of the ERRP and are reflected in the products resulting from these panels. After RTF, the Shuttle System TWH will reassess his/her role in all Shuttle Program panels and boards that deal with flight safety issues, including the ERRP.

The Level 2 Panel will ensure that the safety integration function remains at the Program level. It will have representation by all program elements as well as the Engineering Directorate, ITA, and SMA. The Lead ERRP Manager will also assure that Level 3 panels operate in accordance with safety program requirements. The Level 2 Panel exists to oversee and resolve integrated hazards, forwarding them to the System Integration Configuration Board (SICB), and finally to the ITA and the Program Manager for approval.

The Level 3 ERRPs will consist of a Johnson Space Center (JSC) Panel (Orbiter/extravehicular activity/government-furnished equipment/integration responsibility), a Marshall Space Flight (MSFC) Center Panel (External Tank/Reusable Solid Rocket Motor/Solid Rocket Booster/Space Shuttle Main Engine responsibility), and a Kennedy Space Center (KSC) Panel (ground servicing equipment/Ground Ops responsibility). As presently defined, the Level 3 Panels will be chaired by the independent SMA Directorates at each Space Operations Center, again with representation by trusted agents at these panels.

The Space Operations Mission Directorate Space Shuttle Certificate of Flight Readiness process is being updated to clearly show the new SMA, Integration, and ITA roles and responsibilities. Part of that will be a requirement for concurrence by the Chief Safety and Mission Assurance Officer on the flight readiness statement as a constraint to mission approval. Also, to clear up another ambiguity present in the system at the time of the *Columbia* accident, the JSC SMA Manager will not have a "third hat" as delegated NASA Headquarters OSMA representative on the Mission Management Team. An OSMA representative (the OSMA Shuttle Point of Contact (POC)) will fill that role in an advisory/functional oversight role.

Integration of the New ITA and SMA (R7.5-1/R7.5-2)

In a practical sense, the people that perform the responsibilities of SMA and the ITA need to be involved within a program or project beginning in the early stages and remain involved for the life of the program or project. R7.5-1 from the CAIB Report defined what activities at the program level must be clearly under formal ITA authority. At the same time, Chapter 7 discussion makes it clear that the SMA organization must be independent of the program and technically capable to provide proper check-and-balance with the program. Finally, the SMA organization must be able to perform its assurance functions in support of but independent of both program and engineering organizations.

In response to R7.5-1, NASA named the Chief Engineer to be the ITA. And that authority is delegated fully to responsible individuals who hold warrants under ITA authority for systems and engineering disciplines. Fundamentally, this concept brings a "balance of power" to program management such that the ITA sets technical requirements, the programs execute to that set of technical requirements, and SMA assures the requirements are satisfied. This means that the ITA owns the technical requirements and will be the waiver-granting authority for them.

The principal effect of the foregoing is the clear assignment of responsibility for execution of design and engineering, including the safety functions (FMEA, hazards analysis, reliability engineering, etc.) to Engineering with the ITA setting requirements and approving the resulting engineering products. In this context, SMA organizations have the responsibility for independently assuring that delivered products comply with requirements.

System Integration (R7.5-3)

The CAIB found several deficiencies in the organizational approach to Program system engineering integration for the Space Shuttle Program. Their recommendation R7.5-3 calls for a reorganization of the Space Shuttle Integration Office to "make it capable of integrating all elements of the Space Shuttle Program, including the Orbiter." The CAIB concluded, "…deficiencies in communication…were a foundation for the *Columbia* accident. These deficiencies are byproducts of a cumbersome, bureaucratic, and highly complex Shuttle Program structure and the absence of authority in two key program areas that are responsible for integrating information across all programs and elements in the Shuttle program."

Integration Definition

NASA defines Integration as a system engineering function that combines the technical efforts of multiple system elements, functions, and disciplines to perform a higher-level system function in a manner that does not compromise the integrity of either the system or the individual elements. The Integration function assesses, defines, and verifies the required characteristics of the interactions that exist between multiple system elements, functions, and disciplines, as these interactions converge to perform a higher-level function.

Space Shuttle Systems Engineering and Integration Office

The SSP Manager strengthened the role of the Shuttle Integration Office to make it capable of integrating all of the elements of the SSP, including the Orbiter Project. The SSP restructured its Shuttle Integration Office into a Space Shuttle Systems Engineering and Integration Office (SEIO). The SEIO Manager now reports directly to the SSP Manager, thereby placing the SEIO at a level in the Space Shuttle organization that establishes the authority and accountability for integration of all Space Shuttle elements. The new SEIO charter clearly establishes that it is responsible for the systems engineering and integration of flight performance of all Space Shuttle elements. The number of civil service personnel performing analytical and element systems engineering and integration in the SEIO was doubled by acquiring new personnel from the JSC Engineering and Mission Operations Directorates and from outside of NASA. The role of the System Integration Plan (SIP) and the Master Verification Plans (MVPs) for all design changes with multi-element impact has been revitalized. The SEIO is now responsible for all SIPs and MVPs. These tools will energize SEIO to be a proactive function within the SSP for integration of design changes and verification.

SIPs and MVPs have been developing for all major RTF design changes that impact multiple Shuttle elements.

Orbiter Project Office

The Space Shuttle Vehicle Engineering Office is now the Orbiter Project Office, and its charter is amended to clarify that SEIO is now responsible for integrating all flight elements. NASA reorganized and revitalized the Integration Control Board (ICB). The Orbiter Project Office is now a mandatory member of the ICB. The Space Shuttle Flight Software organization was moved from the Orbiter Project into the SEIO. This reflects the fact that the Shuttle Flight Software Office manages multiple flight element software sources besides the Orbiter.

Integration of Engineering at Centers

All SSP integration functions at MSFC, KSC, and JSC are now coordinated through the SEIO. Those offices receive technical direction from the SSP SEIO. The former MSFC Propulsion Systems Integration office is now called the Propulsion Systems Engineering and Integration (PSE&I) office. The PSE&I is increasing its contractor and civil servant technical strength and its authority within the Program. Agreements between the PSE&I Project Office and the appropriate MSFC Engineering organizations are being expanded to enhance anomaly resolution within the SSP.

Integrated Debris Environments/Certification

The SEIO is also responsible for generation of all natural and induced design environments analyses. Debris is now treated as an integrated induced environment that will result in element design requirements for generation limits and impact tolerance. All flight elements are being re-evaluated as potential debris generators. Computations of debris trajectories under a wide variety of conditions will define the induced environment due to debris. The Orbiter Thermal Protection System will be recertified to this debris environment, as will the systems of all flight elements.

Improving Engineering Integration Agency-wide

NASA has a broad range of programs, projects, and research activities with varying scope that are distributed within and between individual NASA Centers. NASA Headquarters, through the Office of the Chief Engineer, has established the policies that govern Program management, which include the policies for system integration functions as related to the project lifecycle. NASA will assess the effectiveness of integration functions for all of its programs and projects. Further, the policies that govern integration will be assessed and strengthened, as appropriate, to apply to all programs and projects.

FORWARD WORK

Technical Authority is operating across the Agency with major programs such as Space Shuttle and ISS having TWHs who are executing their responsibilities. Independent SMA, as described, has been implemented across NASA. Engineering and Safety Standards are being assessed to determine their applicability to the TA. The Space Shuttle reorganization baselined the integration changes within the SSP. Cultural considerations and further improvements will be included in these overall implementations as they are evolved and understood.

NASA will submit an annual update to Congress of the status of the R9.1-1 plan.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
TA issues policies and warrants	Completed	Initial policy/warrants developed
SSP integrated with TA	Completed	TA in place for RTF
Annual reports to Congress	Sep 05	Annual report describing R9.1-1 Plan progress

Columbia Accident Investigation Board

Recommendation 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]

Note: The Stafford-Covey Return to Flight Task Group held a plenary session on December 15, 2004, and NASA's progress toward answering this recommendation was reviewed. The Task Group agreed the actions taken were sufficient to fully close this recommendation.

BACKGROUND

Closeout photography is used, in part, to document differences between actual hardware configuration and the engineering drawing system. The *Columbia* Accident Investigation Board (CAIB) recognized the complexity of the Shuttle drawing system and the inherent potential for error and recommended to upgrade the system (ref. CAIB Recommendation 10.3-2).

Some knowledge of vehicle configuration can be gained by reviewing photographs maintained in the Kennedy Space Center (KSC) Quality Data Center film database or the digital Still Image Management System (SIMS) database. NASA now uses primarily digital photography. Photographs are taken for various reasons, such as to document major modifications, visual discrepancies in flight hardware or flight configuration, and vehicle areas that are closed for flight. NASA employees and support contractors can access SIMS. Prior to SIMS, images were difficult to locate, since they were typically retrieved by cross-referencing the work-authorizing document that specifies them.

NASA IMPLEMENTATION

NASA formed a Photo Closeout Team consisting of members from the engineering, quality, and technical communities to identify and implement necessary upgrades to the processes and equipment involved in vehicle closeout photography. KSC closeout photography includes the Orbiter, Space Shuttle Main Engine, Solid Rocket Boosters, and External Tank based on Element Project requirements. The Photo Closeout Team divided the CAIB action into two main elements: (1) increasing the quantity and quality of closeout photographs, and (2) improving the retrieval process through a user-friendly Web-based graphical interface system (figure 10.3-1-1).

Increasing the Quantity and Quality of Photographs

Led by the Photo Closeout Team, the Space Shuttle Program (SSP) completed an extensive review of existing closeout photo requirements. This multi-center, multi-element, NASA and contractor team systematically identified the deficiencies of the current system and assembled and prioritized improvements for all Program elements. These priorities were distilled into a set of revised requirements that has been incorporated into Program documentation. Newly identified requirements included improved closeout photography of extravehicular activity tool contingency configurations and middeck and payload bay configurations. NASA has also added a formal photography work step for KSC-generated documentation and mandated that photography of all Material Review Board (MRB) reports be archived in the SIMS. These MRB problem reports provide the formal documentation of known subsystem and component discrepancies, such as differences from engineering drawings.

To meet the new requirements and ensure a comprehensive and accurate database of photos, NASA established a baseline for photo equipment and quality standards, initiated a training and certification program to ensure that all operators understand and can meet these requirements, and improved the SIMS. To verify the quality of the photos being taken and archived, NASA has developed an ongoing process that calls for SIMS administrators to continually audit the photos being submitted for archiving in the SIMS. Operators who fail to meet the photo requirements will be decertified pending further training. Additionally, to ensure the robustness of the archive, poor-quality photos will not be archived.

NASA determined that the minimum resolution for closeout photography should be 6.1 megapixels to provide the necessary clarity and detail. KSC has procured 36 Nikon 6.1 megapixel cameras and completed a test program in cooperation with Nikon to ensure that the cameras meet NASA's requirements.

Improving the Photograph Retrieval Process

To improve the accessibility of this rich database of Shuttle closeout images, NASA has enhanced SIMS by developing a Web-based graphical interface. Users will be able to easily view the desired Shuttle elements and systems and quickly drill down to specific components, as well as select photos from specific Orbiters and missions. SIMS will also include hardware reference drawings to help users identify hardware locations by zones. These enhancements will enable the Mission Evaluation Room (MER) and Mission Management Team to quickly and intuitively access relevant photos without lengthy searches, improving their ability to respond to contingencies.

To support these equipment and database improvements, NASA and United Space Alliance (USA) have developed a training program for all operators to ensure consistent photo quality and to provide formal certification for all camera operators. Additional training programs have also been established to train and certify Quality Control Inspectors and Systems Engineering personnel; to train Johnson Space Center (JSC) SIMS end users, such as staff in the MER; and to provide a general SIMS familiarization course. An independent Web-based SIMS familiarization training course is also in development.

STATUS

NASA has revised the Operation and Maintenance Requirements System (OMRS) to mandate that general closeout photography be performed at the time of the normal closeout inspection process and that digital photographs be archived in SIMS. Overlapping photographs will be taken to capture large areas. NSTS 07700 Volume IV and the KSC MRB Operating Procedure have also been updated to mandate that photography of visible MRB conditions be entered into the SIMS closeout photography database. This requirement ensures that all known critical subsystem configurations that differ from Engineering Drawings are documented and available in SIMS to aid in engineering evaluation and on-orbit troubleshooting.

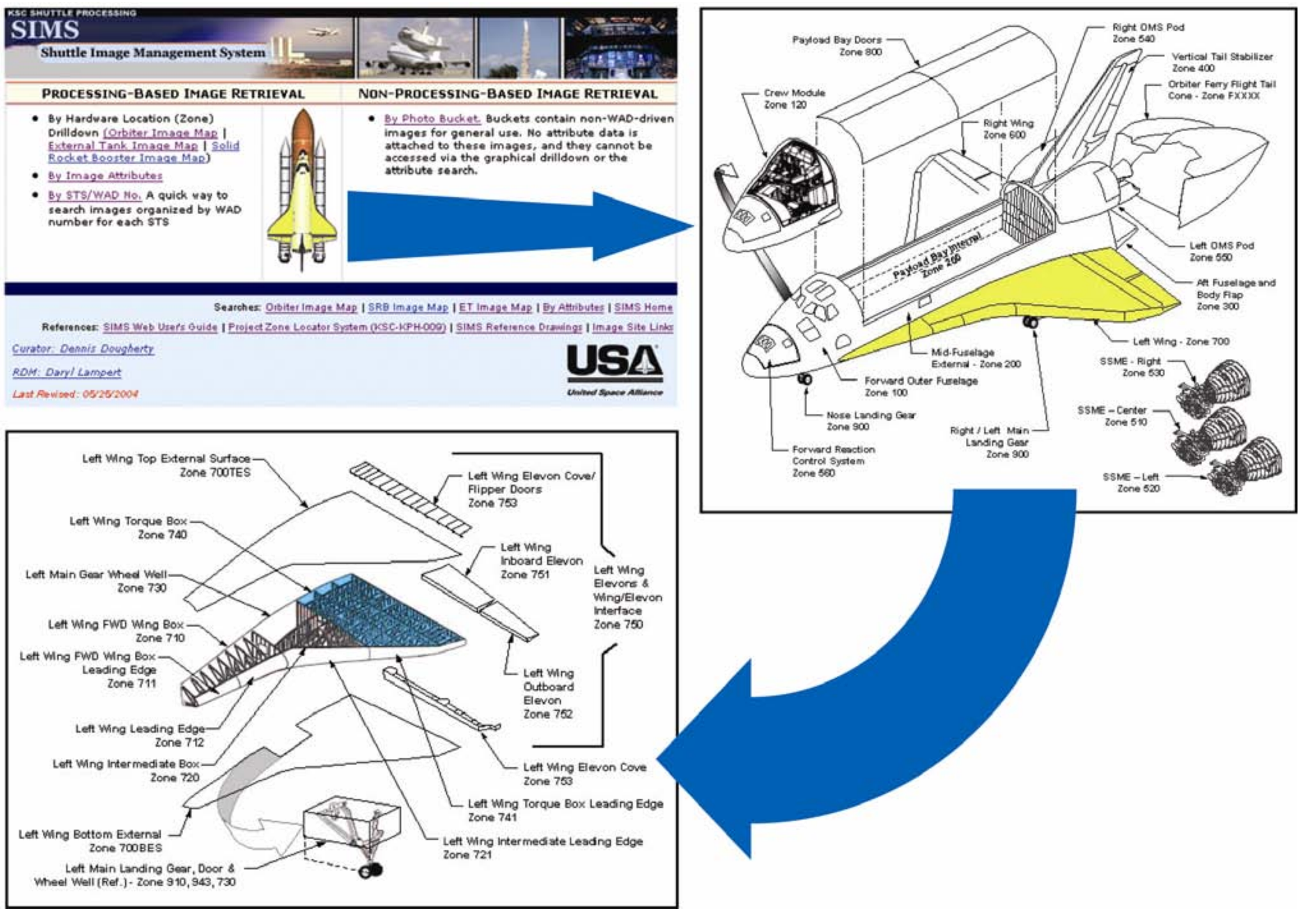


Figure 10.3-1-1. Enhanced SIMS graphic interface.

The revised Shuttle Program closeout photography requirements are documented in RCN KS16347R1 to OMRS File II, Volume I S00GEN.625 and S00GEN.620. Additionally, NASA Quality Planning Requirements Document (QPRD) SFOC-GO0007 Revision L and USA Operation Procedure USA 004644, "Inspection Points and Personnel Traceability Codes," were updated to be consistent with the revised OMRS and QPRD documents. The upgraded SIMS is operational and available for use by all SSP elements. On October 29, 2004, SIMS was successfully used during an inter-center Launch Countdown Simulation with the KSC Launch Team, JSC Flight Control Team, MER, Systems Engineering and Integration Office, and Huntsville Operations Support Center. As a part of the simulation scenario, the SIMS was accessed by participating organizations, and was used to retrieve and view photos to verify the configuration of an Orbital Maneuvering System Pod flight cap installed on the Orbiter.

Training for critical personnel is complete, and will be ongoing to ensure the broadest possible dissemination within the user community. Formal SIMS training has been provided to JSC MER and Marshall Space Flight Center (MSFC) personnel. Photographer training is complete and training classes are held regularly for any new or existing employees needing the certification. SIMS computer-based training (CBT) has been developed and released. Use of SIMS has been successfully demonstrated in a launch countdown simulation at KSC, which included participation from the KSC Launch Team, JSC Flight Control Team, MER, MSFC Huntsville Operations and Support Center (HOSC), and Systems Engineering & Integration (SE&I). Implementation of requirements into KSC operational procedures is continuing.

In July 2004, the Stafford-Covey Return to Flight Task Group reviewed NASA's progress and agreed to conditionally close this recommendation. The full intent of CAIB Recommendation 10.3-1 has been met and full closure of this recommendation was achieved in December 2004.

FORWARD WORK

None.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
KSC	Feb 04 (Completed)	Develop SIMS drilldown and graphical requirements
SSP	Apr 04 (Completed)	Projects transmit photo requirements to KSC Ground Operations
KSC	May 04 (Completed)	Complete graphical drilldown software implementation
KSC	Jun 04 (Completed)	Develop/complete SIMS training module
KSC	Jul 04 (Completed)	Provide training to MER. Demonstrate SIMS interface to JSC/MSFC
KSC	Aug 04 (Completed)	SIMS CBT course development and deployment. (SIMS familiarization course was provided as needed until CBT was completed)
KSC	Aug 04 (Completed)	Photographer training
SSP	Oct 04 (Completed)	S0044 Launch Countdown Simulation run set for 10/29 with full support from the KSC Launch Team, JSC Flight Control Team, MER, MSFC HOSC, and SE&I

Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 2

The Space Shuttle Program will evaluate relative risk to the public underlying the entry flight path. This study will encompass all landing opportunities from each inclination to each of the three primary landing sites.

BACKGROUND

The *Columbia* accident highlighted the need for NASA to better understand entry overflight risk. In its report, the *Columbia* Accident Investigation Board (CAIB) observed that NASA should take steps to mitigate the risk to the public from Orbiter entries. Before returning to flight, NASA is dedicated to understanding and diminishing potential risks associated with entry overflight, a topic that is also covered in CAIB Observations 10.1-2 and 10.1-3.

NASA IMPLEMENTATION

All of the work being done to improve the safety of the Space Shuttle also reduces the risk to the public posed by any potential vehicle failures during ascent or entry. These technical improvements will be paired with operational changes to further reduce public risk. These operational changes include improved insight into the Orbiter's health prior to entry; new flight rules and procedures to manage entry risk; and landing site selection that factors in public risk determinations as appropriate.

The overflight risk from impacting debris is a function of three fundamental factors: (1) the probability of vehicle loss of control (LOC) and subsequent breakup, (2) surviving debris, and (3) the population under the entry flight path. NASA has identified the phases of entry that present a greater probability of LOC based on elements such as increased load factors, aerodynamic pressures, and thermal conditions. Other factors, such as the effect of population sheltering, are also considered in the assessment. The measures undertaken to improve crew safety and vehicle health will result in a lower probability of LOC, thereby improving the public safety during entry overflight.

NASA has conducted a study of the public risks associated with entry to its three primary landing sites: Kennedy Space Center (KSC) in Florida; Edwards Air Force Base (EDW) in California; and White Sands Space Harbor/Northrup (NOR) in New Mexico. We have evaluated the full range of potential ground tracks for each site and conducted sensitivity studies to assess the overflight risk for each.

NASA is currently incorporating population overflight, as well as crew considerations, into the entry flight rules that guide the flight control team's selection of landing opportunities.

STATUS

For NASA's risk assessment of the Space Shuttle landing tracks, more than 1200 entry trajectories were simulated for all three primary landing sites from the Space Shuttle orbit inclination of 51.6° for International Space Station flights. The full range of entry crossrange[1] possibilities to each site was studied in increments of 25 nautical miles for all ascending (south to north) and descending (north to south) approaches. Figure SSP 2-1 displays the ground tracks simulated for the 51.6° inclination orbit. The results indicate that some landing opportunities have an increased public risk compared to others.

The Space Shuttle Program (SSP) has recommended that the current landing site priorities be maintained, and that KSC remain our primary landing site. NASA will use operational methods and vehicle safety improvements implemented in preparation for return to flight (RTF) to manage the risk to the public posed by LOC during overflight. NASA will develop Flight Rules to avoid certain opportunities to abate risk to the general public when feasible and while satisfying other landing site selection priorities for weather, consumables, runway conditions, and entry constraints.

NASA Headquarters (HQ) released a draft policy on ensuring public safety during all phases of space flight missions. The policy is currently under review by all stakeholders.

[1]Entry crossrange is defined as the distance between the landing site and the point of closest approach on the orbit ground track. This number is operationally useful to determine whether or not the landing site is within the Shuttle's entry flight capability for a particular orbit.

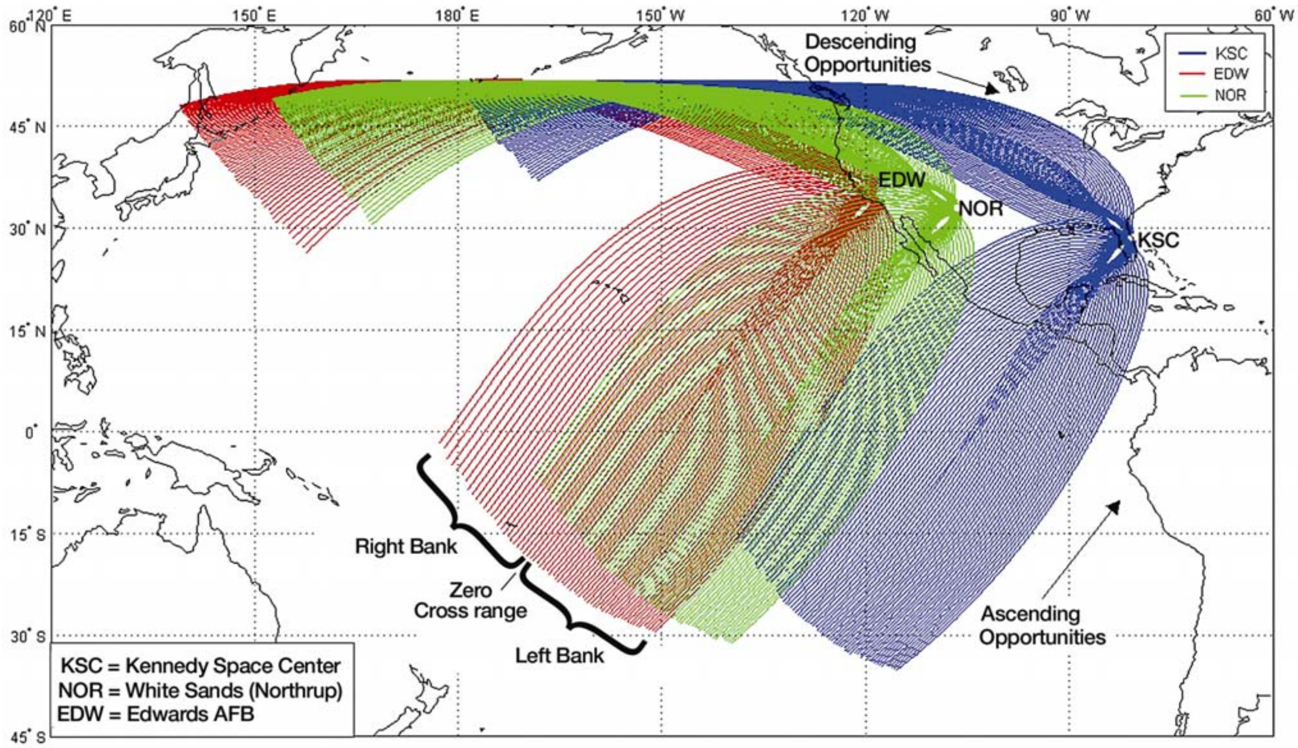


Figure SSP 2-1. Possible entry ground tracks from 51.6° orbit inclination. Blue lines are landing at KSC, green at NOR, red at EDW.

FORWARD WORK

The Johnson Space Center, the Chief Safety and Mission Assurance Officer at NASA HQ, and the Agency Range Safety Program will coordinate activities and share all analyses, research, and data obtained as part of this RTF effort. This shared work is being applied to the development of an Agency Range Safety Policy addressing public risk for all phases of space flight missions.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Jul 03 (Completed)	Preliminary results to RTF Planning Team and SSP Program Requirements Control Board (PRCB)
SSP	Sep 03 (Completed)	Update to RTF Planning Team and SSP PRCB
SSP	Jan 04 (Completed)	Update to RTF Planning Team and SSP PRCB
SSP	Jun 04 (Completed)	Update to SSP PRCB
SSP	Jun 04 (Completed)	Entry risk overview to NASA HQ
SSP	Dec 04 (Completed)	Report to SSP PRCB
NASA HQ	Feb 05 (Completed)	Report to HQ Ops Council
NASA HQ	Spring 2005	Agency Range Safety policy approval

Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 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 that would reduce the debris risk. NASA will also review all Program baseline debris requirements to ensure appropriateness and consistency.

BACKGROUND

A review of critical debris potential is necessary to prevent the recurrence of an STS-107-type failure. NASA is improving the end-to-end process of predicting debris impacts and the resulting damage.

NASA IMPLEMENTATION

NASA will analyze credible debris sources from a wide range of release locations to predict the impact location and conditions. It will develop critical debris source zones to provide maximum allowable debris sizes for various locations on the vehicle. Debris sources that can cause significant damage may be redesigned. Critical impact locations may also be redesigned or debris protection added.

A list of credible ascent debris sources has been compiled for each Shuttle Program hardware element—Solid Rocket Booster, Reusable Solid Rocket Motor, Space Shuttle Main Engine, External Tank, Orbiter, and the pad area around the vehicle at launch. Potential debris sources have been identified by their location, size, shape, material properties, and, if applicable, likely time of debris release. This information will be used to conduct a debris transport analysis to predict impact location and conditions, such as velocities and relative impact angles.

NASA will analyze over two hundred million debris transport cases. These will include debris type, location, size, and release conditions (freestream Mach number, initial velocity of debris piece, etc.).

STATUS

All hardware project and element teams have identified known and suspected debris sources originating from the flight hardware. The debris source tables for all of the propulsive elements mentioned above have been formally reviewed and approved. The debris source tables for the remaining two flight elements, the External Tank and the Orbiter, are in the final steps of review before being baselined. The pad environment table was added after work had commenced on the flight elements and is nearing completion.

The debris transport tools have been completely rewritten, and the results have been peer-reviewed. NASA has completed the transport analysis for the initial 16 debris cases; the resulting data have been provided to the Space Shuttle Program (SSP) elements for evaluation. Preliminary damage tolerance assessments are in work, and the initial set of allowable debris limits for ET foam has been established and is being baselined. A second set of debris transport cases was initiated in October 2004, with an updated methodology that reduces assumptions and unknowns in the first round.

NASA will analyze one final set of debris transport cases in March 2005. These cases represent the final updates to debris assessment inputs as provided by the External Tank, Orbiter, Space Shuttle Main Engine, and Solid Rocket Booster projects.

NASA has also completed a supersonic wind tunnel test at the NASA Ames Research Center. This test validated the debris transport flow fields in the critical Mach number range. Preliminary results show excellent agreement between wind tunnel results and analytically derived flow field predictions.

Interim results of these analyses have already helped the Shuttle Program to respond to the *Columbia* Accident Investigation Board recommendations, such as those on External Tank modifications (R3.2-1), Orbiter hardening modification (R3.3-2), and ascent and on-orbit imagery requirements (R3.4-1 and R3.4-3).

FORWARD WORK

NASA will continue to update its transport analyses as SSP elements increase the fidelity of debris shedding material characteristics. As a part of this process, applicable mass and density ranges will be refined.

The results of the final set of debris transport analyses will be provided to all SSP elements for their analysis of debris impact capability. Updates to the impact and damage tolerance capabilities will be used to increase the fidelity of debris risk assessment.

SCHEDULE

This is an extensive action that will take a year or more to fully complete. The preliminary schedule, included below, is dependent on use of current damage assessment tools. If additional testing and tool development are required, it may increase the total time required to complete the action.

Responsibility	Due Date	Activity/Deliverable
SSP	Jul 03 (Completed)	Elements provide debris history/sources
SSP	Nov 03 (Completed)	Begin Return to Flight Debris Transport analyses
SSP	Dec 04 (Completed)	Complete second set of Debris Transport analyses
SSP	Mar 05	Complete final round of Debris Transport analyses
SSP	Mar/Apr 05	Summary report/recommendation to PRCB

Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 10

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

Note: NASA is closing this observation through the formal Program Requirements Control Board process. The following summary details NASA's response to the Space Shuttle Program (SSP) action and any additional work NASA intends to perform beyond the SSP action.

BACKGROUND

The SSP Program Requirements Control Board has directed all of its projects and elements to review their internal Contingency Action Plans (CAPs) for ways to improve their emergency response processes.

NASA IMPLEMENTATION

The SSP has updated and approved the Program-level CAP to reflect the lessons learned from the Columbia accident. SSP projects and elements are updating their subordinate plans as required to reflect changes to the Program CAP. The Program document has been distributed to all NASA Centers that support human space flight, and orientation training has been conducted across the SSP. A simulation to exercise a realistic contingency situation of the CAP was successfully completed in January 2005.

In implementing changes to the CAP, the SSP incorporated many of the specific lessons learned from the *Columbia* experience while striving to maintain a generic plan that would be useful in a wide range of potential contingency situations. The resulting document is optimized to serve as a rigorous first-response checklist, then to give a menu of possible longer-term response outlines from which to choose based upon the severity of the contingency, its location, and the involvement and responsibilities of other federal, state, and local agencies and foreign governments. Structured responses to Space Shuttle launch contingencies such as trans-oceanic aborts and East Coast abort landings have been retained in the appropriate appendices.

STATUS

Closed.

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

Space flight is not a risk-free endeavor. All major space flight missions, particularly those going to orbit or deeper into space or returning to Earth from space, pose some level of risk to uninvolved people. No matter how small, there is always some potential for failure during flight. If a failure occurs, there will be a possibility of injuring the general public. Overall, our safety approach ensures that any risk to the public associated with space flight is identified and controlled.

People knowingly and unknowingly accept risk throughout their daily lives. Common sources of risk include driving in an automobile, participating in sports, and potential exposure to hazards in the home and the workplace. Our goal is to ensure that a space flight does not add significantly to the public's overall risk of injury. A decision to accept greater public risk may be appropriate if the benefits of the mission are great. Such a decision is based on a comprehensive assessment of the risks and a clear understanding of the benefits associated with taking those risks.

As the government agency directing or controlling space flight operations, NASA is legally responsible for public safety during all phases of the operation. Throughout its history, NASA has met this responsibility. No NASA space flight has ever caused an injury to any member of the general public.

Historically, NASA has had a general risk management policy designed to protect the public as well as NASA personnel and property, codified in NASA Policy Directive (NPD) 8700.1A. This policy calls for NASA to implement structured risk management processes using qualitative and quantitative risk-assessment techniques to make decisions regarding safety and the likelihood of mission success. The policy requires program managers to implement risk management policies, guidelines, and standards within their programs. Although this Agency-level risk policy does not specifically address range flight operations, individual NASA safety organizations, such as those at Wallops Flight Facility and Dryden Flight Research Center, have well-established public and workforce risk management requirements and processes at the local level. Also, NASA has always worked closely with the safety organizations at the U.S. Air Force's Eastern and Western Ranges to satisfy public risk requirements during Space Shuttle and other NASA space flight operations.

The *Columbia* Accident Investigation Board (CAIB) suggested that NASA should develop and implement a public risk acceptability policy. In making this suggestion, the CAIB did not find NASA's current approach to public risk to be in need of immediate attention and did not make this a return to flight recommendation. However, NASA has pursued the development and implementation of this policy as part of its efforts to "raise the bar" and has worked toward the goal of completing this effort for return to flight.

NASA IMPLEMENTATION

Policy Overview

NASA has developed a public risk policy, which incorporates the Agency's approach for identifying and managing the risk to the general public that is associated with space flight operations, such as launch and entry of space flight vehicles and the operation of crewless aircraft. This new Agency-level policy is documented in Chapter 3 of NASA Procedural Requirement (NPR) 8715.XX, NASA Range Safety Program. NASA intends to implement this policy for the upcoming Space Shuttle return to flight and all future NASA space flight missions.

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 established a risk policy working group with members from throughout the Agency and chartered the group to perform the initial development and coordination of the new public risk policy. The working group coordinated with the interagency range safety community and consulted with experts in applying public and workforce risk assessment to the operation of experimental and developmental vehicles. The CAIB's lead investigator for the issue of public risk participated in many of the working group's activities. This inclusive approach helped to ensure that NASA's new policy fully responds to the related CAIB findings and observations.

The NASA public risk policy incorporates a widely accepted risk management approach, which has been used successfully at United States launch and landing sites for addressing the risk to the public associated with space flight operations. The policy includes requirements for risk assessment, risk mitigation, and acceptance/disposition of risk to the public and workforce. The policy incorporates performance standards for assessing risk and contains acceptable risk criteria. Finally, the policy requires review and approval by NASA Senior Management for any proposed operations where the risk to the public or workforce might increase above the public risk criteria.

Public risk policies in general incorporate established risk criteria that a majority of the affected operations are expected to satisfy. Such criteria define a standard level of risk that the approval authority, in this case the NASA Administrator, accepts for normal, day-to-day operations. The establishment of public risk criteria helps to facilitate the acceptance of risk in operational environments where it would be impractical for upper management to be involved in making every risk acceptance decision on an individual basis.

There are primarily two types of risk criteria that the public risk policy must address. The first type of risk is referred to as "individual risk." The second type of risk is referred to as "collective risk." The NASA public risk policy incorporates criteria for both types of risk. NASA's public risk criteria are consistent with those used throughout the government, the commercial range community, and with other industries whose activities are potentially harmful to the general public.

The measurement for individual risk represents the number of times that an individual at a specific location could experience a serious injury for a single event, such as the launch or entry of a Space Shuttle, if a large number of events could be carried out under identical circumstances.

> For example: the public individual risk criterion used throughout the space flight operations community and in the new NASA policy is less than or equal to one in a million. Translation: if an individual were to attend one million identical launches, that person would experience a serious injury less than or equal to once (i.e., a relatively low risk). The individual risk criterion is typically enforced by establishing a "keep-out" zone for each launch or entry such that if all individuals remain outside the keep-out zone, individual risk will satisfy the criterion. Note: All NASA launches and entries, including Shuttle launches and entries have always, and will continue to employ keep-out zones in the vicinity of the launch and landing sites where the risk approaches the one-in-a-million threshold. Enforcement of these keep-out zones ensures that the one-in-a-million individual risk criterion is satisfied for all public including visitors to a NASA launch or landing site.

The measurement for collective risk is the average number of serious injuries expected within a defined population for a single event, such as a Space Shuttle launch or entry, if a large number of events could be carried out under identical circumstances. Although the individual risk to members of an exposed population may be very low for a single event, as the number of people within the exposed population increases, the collective risk will increase. The collective risk can be controlled to a reasonable level by controlling the exposed population.

> For example: if a group of 100,000 people attends a launch and all of the people are located at the boarder of the keep-out zone such that each person has an individual risk equal to one in a million, the collective risk for the group would equate to one in a million multiplied by 100,000 or an average of one serious injury within the group in 10 launches. Of course this is an exaggerated example, but it serves to demonstrate how collective risk will continue to increase as the number of people that have any significant individual risk continues to increase. Placing a collective public risk limit on a space flight provides the impetus for the Agency to consider the number of people exposed to a given hazardous condition and place limits on the exposed population.

The criteria for individual and collective risk are established at levels considered acceptable for a majority of the expected operations. Within our space flight community, public risk is assessed to ensure that the risk is understood and is within acceptable limits for day-to-day operations. As with all risk policies, NASA's public risk policy incorporates processes for review and acceptance of any risk that exceeds the established criteria. NASA Senior Management will make such decisions when warranted based on a thorough understanding of any additional risk and the benefits to be derived from taking the additional risk. If an operation cannot meet our public risk criterion after all reasonable risk-reduction strategies have been employed, a variance process is most commonly used to determine whether any additional reasonable risk is deemed acceptable for the specific operation. Within NASA, the ultimate authority for accepting any risk above the established criteria lies with the NASA Administrator, who may delegate related authority. Authority for dispositioning variance requests to the public risk policy is delegated to the Independent Technical Authority and the Center Director or Headquarters-designated manager responsible for the vehicle program with concurrence by the official responsible for the range, launch site, or landing site. Note that NASA does not foresee the need to process any variance to the new risk policy for return to flight or any future Space Shuttle flight.

Space Shuttle Launches

NASA will continue to coordinate fully with the Air Force range safety community to determine the risk to the public associated with each Space Shuttle launch from the Kennedy Space Center (KSC). NASA and the Air Force have worked closely to improve the input data used in the risk assessments to ensure that results are based on the best possible estimate of vehicle nominal and off-nominal behavior. NASA has updated personnel categories and ensured workforce and visitor locations on KSC are accurately modeled. For each Shuttle launch, the Air Force will continue to use its risk analysis tools to provide a best estimate of the risks to the general public, visitors to the launch site, and the workforce. The Air Force, in coordination with NASA, will continue to update these models and to ensure the latest technologies and input data are employed.

All Space Shuttle launches are expected to satisfy the public risk criteria contained in NASA's new policy. Shuttle launches have always satisfied Air Force public risk criteria for individual risk as they have always satisfied Air Force collective risk criteria for the general public outside of KSC. Those criteria are reflected in NASA's new policy. NASA has not previously applied a collective risk criterion to people on KSC during Shuttle launches. Application of a collective public risk criterion to people on KSC represents the primary change affecting launch that will be in place for Shuttle return to flight.

The new NASA policy incorporates an annual public collective risk criterion of one serious injury in a thousand years, which is a historical basis for the per-launch public risk criteria used by the federal ranges. Future Space Shuttle launches will satisfy this annual criterion. NASA expects to average five Shuttle launches per year to complete the International Space Station. One-in-a-thousand years divided by an average of five launches per year yields a per-launch risk criterion of 200 in a million. The policy limits collective risk to the public outside KSC to 30 in a million per launch, which remains consistent with the Air Force public launch risk criterion enforced by the Eastern Range. This leaves a collective risk budget of 170 in a million that NASA will apply to people on KSC during a Shuttle launch. A NASA KSC management review board will evaluate the risk assessment results provided by the Air Force for each Shuttle launch and determine the appropriate risk mitigation options needed to ensure that the risk criteria are satisfied. This will include identifying where people may be located on KSC during a launch and how many will be allowed at each location.

NASA's implementation of the public risk policy will ensure that any risk associated with attending a Shuttle launch at KSC is kept at a reasonable level. Individual risk to the vast majority of the public, those who are not on KSC, will be significantly lower than the one-in-a-million individual risk criterion. Satisfying the collective risk criterion will result in limitations on the numbers of visitors allowed to attend a Shuttle launch at KSC and where these visitors can be located. However, NASA is confident that, through proper establishment of viewing sites and close controls on the numbers of people at each site, KSC will continue to accommodate a reasonable number of visitors for each Shuttle launch, consistent with NASA's mission to inspire the next generation of explorers.

Space Shuttle Entries

Assessment of public risk associated with Orbiter entries is a new requirement for the Space Shuttle Program after the *Columbia* accident. Unlike Shuttle launch, for which the Air Force's risk assessment tools and models were previously well established, the Space Shuttle Program has had to develop the tools and models needed to assess entry public risk. Encouraged by the CAIB Report, this has been a significant effort over the past year and a half for NASA civil servant and contractor personnel.

Because the trajectories, failure modes, and hazard characteristics are very different for entry as compared to launch, new and innovative approaches to risk modeling had to be developed. For example, vehicle breakup during a launch failure is typically modeled as instantaneous (i.e., as in an explosion). The *Columbia* accident demonstrated that a high-altitude structural failure of the Orbiter results in a progressive breakup over a relatively long period of time as pieces separate from the vehicle and then even break into smaller pieces as they fall. NASA personnel at the Johnson Space Center developed new modeling techniques capable of accounting for progressive vehicle breakup. Also note that the *Columbia* accident represents just one type failure that can occur during an entry. There are other failure modes, such as potential loss of control late in flight at a relatively low altitude. Such a failure would have vehicle breakup characteristics that are very different from a high-altitude failure. NASA has developed risk assessment models that account for the different failure modes and other contributors to public risk associated with Shuttle Orbiter entries. NASA will perform the public risk assessment for Shuttle Orbiter entries as part of the risk management process, and will continue to update the entry risk models and ensure the latest technologies and input data are employed.

All future NASA entries, including Shuttle Orbiter entries, will satisfy the one-in-a-million individual public risk criterion contained in the new NASA policy. The Shuttle entry risk assessments have demonstrated that a person would have to be standing in an area close to the approach end of the runway during an Orbiter landing for that person's individual risk to exceed the criterion. With establishment of appropriate keep-out zones, NASA will ensure that the individual risk criterion is satisfied during each future entry operation.

With regard to the public collective risk criteria associated with entry operations, the new NASA policy takes a two-part approach. The first part of the entry risk policy applies specifically to Shuttle. This provision recognizes Shuttle's established design and operational constraints, which were developed without a specific requirement for managing public entry collective risk more than 25 years ago. Under this provision, KSC will continue as the Shuttle's primary landing site, with Edwards Air Force Base (EAFB) and White Sands Missile Range (WSMR) as backups. The Space Shuttle Program will implement new flight rules that address the need for public risk abatement in the selection of the landing site for each mission.

The second part of NASA's new entry public collective risk policy contains risk criteria that will apply to vehicles beyond Shuttle. These risk criteria were developed in consultation with the national range community and are intended to serve the Nation's space program into the future as new vehicles are developed and entry operations become more common.

NASA has assessed the relative public collective risk associated with all possible Shuttle entry trajectories into the three landing sites from the International Space Station orbit inclination of 51.6 degrees. On average, entry opportunities into KSC are half the public risk level of entries into EAFB. On average, entry opportunities into WSMR are one-seventh the public risk level of EAFB and one-third the public risk level of KSC. Although entries to WSMR represent a lower overall public collective risk, WSMR does not have the infrastructure needed to safely and efficiently support regular Shuttle landings. WSMR and EAFB are best used as backups in conjunction with the Space Shuttle Program's use of flight rules designed to balance all safety concerns in the selection of a landing site.

The risk to the general public during entry has been significantly reduced for Shuttle return to flight as compared to the past. Most of the improvements developed for return to flight either directly or indirectly serve to improve public safety during entry. For example, we will now have unprecedented capability to inspect and assess the operational status of safety-critical thermal protection systems while on orbit. The flight rules for entry will account for the Orbiter systems' operational status and will balance crew and public safety concerns when selecting among the available entry opportunities and landing sites. NASA is confident that this balanced approach is the wisest. The bottom line is that the Orbiter will normally land at KSC; but if it is compromised in a way that poses a threat to the public, it will land at WSMR.

The criterion for entry collective risk represents the only portion of NASA's new policy that contains a Space Shuttle-specific provision. In addition to this provision, all other aspects of the NASA's public risk policy apply to the Space Shuttle for return to flight.

STATUS

In a series of meetings that culminated on February 15, 2005, the NASA Operations Council approved the range safety risk policy approach and its implementation for Shuttle return to flight. The Council directed that NPR 8715.XX, which contains the detailed policy, be entered into the Agency's formal review and approval process using the NASA Online Directives Information System (NODIS).

FORWARD WORK

The new NASA policy requires that each program document its safety risk management process in a written plan approved by the responsible NASA officials. The Space Shuttle Program will complete its plan and obtain the required approvals for return to flight.

SCHEDULE

Action	March 2005 NODIS Review Cycle
Published Deadline for Submission to NODIS	Mar. 15, 2005
Comments Due	Mar. 28, 2005
Signature Package Prepared	May 13, 2005
Final Signature Expected	Jun 2005

Columbia Accident Investigation Board

Observation 10.7-1

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

Note: NASA is closing this observation through the formal Program Requirements Control Board process. The following summary details NASA's response to the observation and any additional work NASA intends to perform beyond the *Columbia* Accident Investigation Board (CAIB) observation.

BACKGROUND

The Space Shuttle Program has initiated an action to assess the CAIB observations related to corrosion damage in the Space Shuttle Orbiters. This action has been assigned to the Orbiter Project Office.

NASA IMPLEMENTATION

The Orbiter element is in full compliance with this observation. Before the disposition of any observed corrosion on Orbiter hardware, a full action plan is coordinated by the responsible subsystem engineering discipline. To resolve specific corrosion issues, evaluation and/or analysis is performed by the appropriate subsystem, stress, and materials engineers. Investigations into hardware conditions and exposure environments are performed to determine root cause of any corrosion, and nondestructive analysis is used to assist in characterization of the depth and breadth of existing corrosion. Destructive analysis is pursued where appropriate.

In all cases, Space Shuttle requirements mandate that positive safety margins must be retained by Orbiter hardware. To do this, where necessary, affected components may be replaced or supplementary load paths/doublers applied. Any course of action (e.g., leave as-is, application of corrosion preventative compounds, re-work, replace, etc.) must be agreed upon by the appropriate technical communities. Cross-disciplinary reviews of significant corrosion-related issues take place on a regular basis. As new or repeat corrosion issues are discovered, the governing Operations and Maintenance Requirements and Specifications Document is reviewed and modified as appropriate. Future inspection schedules are adjusted accordingly to maintain conservative time intervals.

To support Orbiter corrosion issues and concerns, the Orbiter Corrosion Control Review Board (CCRB) provides an independent technical review of ongoing corrosion issues. The CCRB has representation from both NASA and NASA contractors in materials and processes engineering, subsystem engineering, and safety and mission assurance.

For "minor" corrosion issues, the Orbiter CCRB may be consulted for a recommendation at the discretion of the subsystem engineer. If the corrosion in question cannot be repaired by the Orbiter Standard Repair Procedure (V-ST-0029) or if reapplication of per print corrosion protective finishes cannot be accomplished or is inadequate, a review by the CCRB is required.

On a case-by-case basis, the engineering review team/CCRB may identify other similar hardware, materials, and locations on the flight vehicles as suspect; this determination results in targeted inspections. In areas where nondestructive analysis is not currently feasible (e.g., under the Thermal Protection System, between faying surface joints, etc.), "sampling" inspections are carried out to quantify the scope and magnitude of the corrosion issue. Analysis is completed to determine whether the corrosion is local or systemic.

Additional funding for augmentation of Orbiter corrosion control activities was authorized in May 2004 and extends through early fiscal year 2006. Thereafter, the expanded efforts will be covered within scope as part of the Space Flight Operations Contract extension. This authorization implements proactive corrosion control measures to ensure continued safety and sustainability of Orbiter hardware throughout the planned Shuttle Program Service Life, including identification of improvements to nondestructive evaluation techniques.

STATUS

Complete.

FORWARD WORK

None.

Columbia Accident Investigation Board

Observation 10.7-2

Long-term corrosion detection should be a funding priority.

Note: NASA is closing this observation through the formal Program Requirements Control Board process. The following summary details NASA's response to the observation and any additional work NASA intends to perform beyond the *Columbia* Accident Investigation Board observation.

BACKGROUND

Both Orbiter engineering and management concur that ongoing corrosion of the Space Shuttle fleet should be addressed as a safety issue. As the Orbiters continue to age, NASA must direct the appropriate level of resources to sustain the expanding scope of corrosion and its impact to Orbiter hardware.

NASA IMPLEMENTATION

Following the *Columbia* accident, the Orbiter Corrosion Control Review Board has been strengthened significantly. Additional funding for augmentation of Orbiter corrosion control activities was authorized in May 2004 and extends through early fiscal year 2006. Thereafter, the expanded efforts will be covered within scope as part of the Space Flight Operations Contract extension. This authorization implemented proactive corrosion control measures to ensure safety and sustainability of Orbiter hardware throughout the planned Space Shuttle Program (SSP) service life. Specific activities addressing corrosion prevention and detection include: developing methods to reduce hardware exposure to corrosion causes; identifying and evaluating the environment of corrosion prone areas and environmental control mitigation options; identifying improved nondestructive evaluation (NDE) techniques; and implementing an industry benchmark team for reducing corrosion and improving NDE methods.

NASA, United Space Alliance, and Boeing are developing and implementing the expanded scope of an effective, long-term corrosion control program. This expanded program will attempt to inspect for, detect, evaluate, trend, and predict corrosion on Orbiter hardware throughout the remainder of the SSP.

STATUS

Complete.

FORWARD WORK

None.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Orbiter Project Office	Completed	Direct appropriate long-term funding (sustained)
Orbiter Project Office	Jun 04 (Completed)	Develop an advanced Orbiter Corrosion Control Program to detect, trend, analyze, and predict future corrosion issues

Columbia Accident Investigation Board

Observation 10.7-3

Develop non-destructive evaluation inspections to find hidden corrosion.

Note: NASA is closing this observation through the formal Program Requirements Control Board (PRCB) process. The following summary details NASA's response to the observation and any additional work NASA intends to perform beyond the *Columbia* Accident Investigation Board (CAIB) observation.

BACKGROUND

An integral part of an effective corrosion control program is the continual development and use of nondestructive evaluation (NDE) tools. The development of tools that explore hidden corrosion is a complex problem.

NASA IMPLEMENTATION

NASA is investigating a wide range of advanced NDE techniques, and has several activities ongoing to use NDE to find hidden corrosion. These activities include:

- Chartered by the NASA, the NDE Working Group (NNWG) has representatives from each of the NASA field centers and affiliated contractors. This group meets periodically to address NASA's short- and long-term NDE needs. In the past, the NNWG has executed efforts to develop NDE techniques directly in support of this subject, such as corrosion under tile. In the future, Orbiter engineering will partner with the NNWG on NDE development work as specific achievable needs are identified.
- An Orbiter NDE working group was established to address both immediate and long-term Orbiter needs. This technical team has become an important resource in support of ongoing Orbiter problem resolutions. This team will attempt to address the need for advanced NDE tools and techniques required to address hidden corrosion.
- United Space Alliance has begun to investigate advanced techniques, such as the Honeywell Structural Anomaly Mapping System, to support both structural assessments as well as hidden corrosion. This technology is currently under assessment for potential certification by the Federal Aviation Administration.
- Johnson Space Center and Marshall Space Flight Center have developed a compilation of hidden corrosion test standards. These standards will be used for future evaluation of potential NDE techniques.

In areas where nondestructive analysis is not currently feasible (e.g., under the Thermal Protection System (TPS), between faying surface joints, etc.), "sampling" inspections are carried out to quantify the scope and magnitude of the particular corrosion issue. Analysis is subsequently completed to determine whether the corrosion is local or systemic.

As an example, the CAIB Report referenced corrosion discovered prior to STS-107 on the *Columbia* vehicle in the lower forward fuselage skin panel and stringer areas (inner surfaces). Subsequently, inspections of the TPS bond line (outer surfaces) identified isolated incidents of localized surface corrosion. This raised concerns regarding a potential threat to the TPS bond-line. As a result, a complete history of previous TPS corrosion inspections, bond-line corrosion indications, bond surface preparation processes and controls, and TPS bond operation materials and processes was reviewed. The review was coordinated jointly between the Materials and Processes, TPS, and Structures engineering organizations with a contributing independent assessment by the Corrosion Control Review Board. This activity resulted in a reversal of previous engineering direction; as a result, damaged Koropon primer is now required to be repaired/reconditioned before tiles are bonded, and NASA authorized development of an extensive multi-year sampling program intended to characterize the magnitude and scope of corrosion occurring under tile.

In May 2004, the Shuttle Program authorized $3.3M of additional funding for augmentation of Orbiter corrosion control activities via PRCB directive S061984R1. This authorization implemented proactive corrosion control measures to ensure continued safety and sustainability of Orbiter hardware throughout the planned Shuttle Program service life, including identification and development of improvements to NDE techniques. Following fiscal year 2006, the expanded Orbiter corrosion control efforts will be covered under the Space Flight Operations Contract extension.

As a part of this expanded program, the current and future Orbiter project needs for NDE will be evaluated for further development. A review of all current activities will be completed and compared with long-term project needs.

FORWARD WORK

None.

STATUS

Complete.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Orbiter Project Office	Jun 04 (Completed)	Develop an advanced Orbiter Corrosion Control Program, chartered to detect, trend, analyze, and predict future corrosion issues. Development of NDE techniques for corrosion detection shall be included in the Program.

Columbia Accident Investigation Board

Observation 10.7-4

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.

Note: NASA is closing this observation through the formal Program Requirements Control Board process. The following summary details NASA's response to the observation and any additional work NASA intends to perform beyond the *Columbia* Accident Investigation Board observation.

BACKGROUND

Historically, inspection intervals for Orbiter corrosion have not been driven by mathematical corrosion rate assessments. In practice, predicting corrosion rates is only effective when the driving mechanism is limited to general surface corrosion in a known environment over a known period of time. To date, general surface corrosion is not an Orbiter problem. Common Orbiter corrosion problems include pitting, crevice, galvanic, and intergranular corrosion attack. These mechanisms are extremely sporadic and inconsistent and present tremendous difficulty in effectively predicting corrosion rates. Environments are complex, including time histories with intermittent exposure to the extreme temperatures and vacuum of space. Also, with a limited data set (three vehicles), it is difficult to develop and use a database with a reasonable standard deviation. Any calculated results would carry great uncertainty.

NASA IMPLEMENTATION

NASA agrees with the importance of understanding when and where corrosion occurs as a first step towards mitigating it. Given the difficulty in establishing trenchant mathematical models of corrosion rates for the multiple Orbiter environments, the NASA/contractor team (through the Orbiter Corrosion Control Review Board (CCRB)) will assess mechanisms, magnitudes, and rates of corrosion occurrence. This can be used to prioritize high corrosion occurrence areas. The CCRB will also target inspections toward low-traffic and/or hard-to-access areas that are not consistently inspected. Furthermore, the CCRB will address predicting the rates of long-term degradation of Orbiter corrosion protection systems (i.e., paints, sealants, adhesives, etc.).

Beyond the original Orbiter design life of 10 years, corrosion inspection intervals have been driven by environment, exposure cycles, time, materials, and configuration without the use of specific corrosion rate predictions. Although not fool-proof, these inspection intervals have generally been extremely conservative. In the few cases where this has not been conservative enough, the scope of concern has been expanded accordingly and the inspection interval requirements have been changed. Moreover, when corrosion is identified, the standard procedure is to immediately repair it. If the corrosion is widespread in an area or a configuration, specific fixes are incorporated (e.g., between faying surfaces/dissimilar metals, etc.) or refurbishments are implemented (e.g., strip and reapplication of primers, etc.). In the few cases where this is not possible, such as when the rework cannot be completed without major structural disassembly, engineering assessments are completed to characterize the active corrosion rate specific to the area of concern, and inspection intervals are assigned accordingly, until the corrosion can be corrected. Relative to the general aviation industry, NASA's approach to corrosion repair is extremely aggressive.

In the past, NASA has worked closely with the U.S. Air Force to review corrosion prevention programs for potential application to the Orbiter Program. Several successes from Air Force programs have already been implemented, such as the use of water wash-downs and corrosion preventative compounds. In the future, the Orbiter CCRB will continue to partner with both industry and the Department of Defense (DoD) to further develop and optimize the Orbiter corrosion control program. To maintain exposure to the current state-of-the-art in this area, the CCRB will participate annually in the NASA/DoD Aging Aircraft Conference.

Following the *Columbia* accident, the Orbiter CCRB has been strengthened significantly. Additional funding for augmentation of Orbiter corrosion control activities was authorized in May 2004 and NASA, United Space Alliance, and Boeing are working to implement an expanded corrosion control program. This authorization implements proactive corrosion control measures to ensure continued safety and sustainability of Orbiter hardware throughout the planned Shuttle Program service life. This activity will include a review of the current state of the art in corrosion control tools and techniques, followed by consideration for implementation into the future Orbiter corrosion control program. Authorized funding extends through early fiscal year 2006 to expand Orbiter corrosion control. Thereafter, the expanded efforts will be covered within scope as part of the Space Flight Operations Contract extension.

STATUS

Complete.

FORWARD WORK

None.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Orbiter Project Office	Completed	Direct appropriate funding to develop a sustained Orbiter Corrosion Control Board.
Orbiter Project Office	Jun 04 (Completed)	Develop an advanced Orbiter Corrosion Control Program to detect, trend, analyze, and predict future corrosion issues.

Columbia Accident Investigation Board

Volume II, Appendix D.a, Quality Assurance Section, Recommendation D.a-12 Crew Survivability

To enhance the likelihood of crew survivability, NASA must evaluate the feasibility of improvements to protect the crew cabin on existing Orbiters.

Note: NASA is closing this recommendation through the formal Program Requirements Control Board (PRCB) process. The following summary details NASA's response to the recommendation and any additional work NASA intends to perform beyond the *Columbia* Accident Investigation Board (CAIB) recommendation.

BACKGROUND

The CAIB found that, in both the *Challenger* and the *Columbia* accidents, the crew cabin initially survived the disintegration of the Orbiter intact.

NASA IMPLEMENTATION

Implementation of this recommendation has been in work since the release of the *Columbia* Accident Investigation Board Report, Volume I. The Space Shuttle Service Life Extension Program II Crew Survivability Sub-panel recognized the need for the Program to continue funding the vehicle forensic analysis and follow-on thermal and structural hardening analysis. This work plays a part not only as resolution to a CAIB Recommendation but also as a component of furthering the technical understanding of the space/atmosphere-aero interface and conveys knowledge capture for future programs.

On July 21, 2004, the Space Shuttle Upgrades PRCB approved the formation of the Space Craft Survival Integrated Investigation Team (SCSIIT). This multidisciplinary team, comprised of JSC Flight Crew Operations, JSC Mission Operations Directorate, JSC Engineering, Safety and Mission Assurance, the Space Shuttle Program, and Space and Life Sciences Directorate, was tasked to perform a comprehensive analysis of the two Shuttle accidents for crew survival implications. The team's focus is to combine data (including debris, video, and Orbiter experiment data) from both accidents with crew module models and analyses. After completion of the investigation and analysis, the SCSIIT will issue a formal report documenting lessons learned for enhancing crew survivability in the Space Shuttle and for future human space flight vehicles, such as the Crew Exploration Vehicle.

The SCSIIT expects analysis to be completed within approximately two years. Space Shuttle-critical flight safety issues will be reported to the PRCB for disposition. Future crewed-vehicle spacecraft will use the products of the multidisciplinary team to aid in developing the crew safety and survivability requirements.

STATUS

The SCSIIT anticipates the final report with recommendations will be issued in September 2006. Fiscal year 2005 (FY05) and FY06 funding has been committed for this team's activities.

FORWARD WORK

None.

Columbia Accident Investigation Board

Volume II, Appendix D.a, Quality Assurance Section, Recommendation D.a-13 RSRM Segment Shipping Security

NASA and ATK Thiokol perform a thorough security assessment of the RSRM segment security, from manufacturing to delivery to Kennedy Space Center, identifying vulnerabilities and identifying remedies for such vulnerabilities.

Note: NASA considers this recommendation closed, and the following summary details NASA's response.

BACKGROUND

During security program assessments at the ATK Thiokol Reusable Solid Rocket Motor (RSRM) Production Facility, the *Columbia* Accident Investigation Board raised concerns about several elements of the overall security program. Most notable of these concerns was protection of completed segments prior to rail shipment to the Kennedy Space Center (KSC).

NASA IMPLEMENTATION

NASA has conducted a full security program vulnerability assessment of the ATK Thiokol RSRM Production Facility, with the goal of identifying and mitigating security vulnerabilities.

NASA security officials, together with ATK Thiokol Security Program officials, performed an assessment of the RSRM security program from RSRM manufacturing to delivery, inspection, and storage at KSC. The assessment included a review of the ATK Thiokol manufacturing plant to the railhead; participation in the rail shipment activities of RSRM segment(s) to or from KSC; regional and local threats; and rotation, processing, and storage facility security at KSC. Based on this assessment, NASA plans to implement a vulnerability mitigation activity.

STATUS

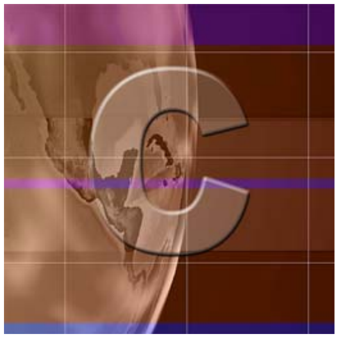
NASA conducted assessments of several key elements of the ATK Thiokol RSRM operation: December 8–12, 2003, ATK Thiokol RSRM Facilities; January 26–27, 2004, KSC RSRM Facilities; and January 30–February 9, 2004, RSRM Railway Transport Route and Operations.

An RSRM Security Assessment briefing was provided by the assessment team lead to both Marshall Space Flight Center Security and RSRM Project in March 2004. The written report was submitted at a later date. The team's assessment concluded that "threat" and "vulnerability" were low and no critical findings were noted.

A number of recommendations to enhance RSRM security were provided for RSRM Project consideration. These recommendations were grouped into three categories: Corinne Site (where RSRM segments are loaded onto rail cars), rail transport, and general operations. The Project assessed the impact and viability of noted recommendations. Those recommendations that the Project agreed would effectively enhance RSRM security were implemented prior to the shipment of flight hardware to KSC (December 2004).

SCHEDULE

This action is considered closed by the Project.



Appendix C: Return to Flight Summary Overview

Note: The Return to Flight Summary was originally written in August 2003 (for the first edition of NASA's Implementation Plan for Space Shuttle Return to Flight and Beyond*) to reflect NASA's initial approach for responding to the Columbia Accident Investigation Board (CAIB) Recommendations and Observations as well as the Space Shuttle Program's Raising the Bar Actions. It has not been updated since its initial publication; therefore, it may contain outdated information. It is included as Appendix C for historical reference only.*

The CAIB Report has provided NASA with the roadmap for moving forward with our return to flight efforts. The CAIB, through its diligent work, has determined the causes of the accident and provided a set of comprehensive recommendations to improve the safety of the Space Shuttle Program. NASA accepts the findings of the CAIB, we will comply with the Board's recommendations, and we embrace the report and all that is included in it. This implementation plan outlines the path that NASA will take to respond to the CAIB recommendations and safely return to flight, while taking into account the Vision for Space Exploration.

At the same time that the CAIB was conducting its assessment, NASA began pursuing an intensive, Agency-wide effort to further improve our human space flight programs. We are taking a fresh look at all aspects of the Space Shuttle Program, from technical requirements to management processes, and have developed a set of internally generated actions that complement the CAIB recommendations.

NASA will also have the benefit of the wisdom and guidance of an independent, advisory Return to Flight Task Group, led by two veteran astronauts, Apollo commander Thomas Stafford and Space Shuttle commander Richard Covey. Members of this Task Group were chosen from among leading industry, academia, and government experts. Their expertise includes knowledge of fields relevant to safety and space flight, as well as experience as leaders and managers of complex systems. The diverse membership of the Task Group will carefully evaluate and publicly report on the progress of our response to implement the CAIB's recommendations.

The space program belongs to the nation as a whole; we are committed to sharing openly our work to reform our culture and processes. As a result, this first installment of the implementation plan is a snapshot of our early efforts and will continue to evolve as our understanding of the action needed to address each issue matures. This implementation plan integrates both the CAIB recommendations and our self-initiated actions. This document will be periodically updated to reflect changes to the plan and progress toward implementation of the CAIB recommendations, and our return to flight plan.

In addition to providing recommendations, the CAIB has also issued observations. Follow-on appendices may provide additional comments and observations from the Board. In our effort to raise the bar, NASA will thoroughly evaluate and conclusively determine appropriate actions in response to all these observations and any other suggestions we receive from a wide variety of sources, including from within the Agency, Congress, and other external stakeholders.

Through this implementation plan, we are not only fixing the causes of the *Columbia* accident, we are beginning a new chapter in NASA's history. We are recommitting to excellence in all aspects of our work, strengthening our culture and improving our technical capabilities. In doing so, we will ensure that the legacy of *Columbia* guides us as we strive to make human space flight as safe as we can.

Key CAIB findings

The CAIB focused its findings on three key areas:

- Systemic cultural and organizational issues, including decision making, risk management, and communication;
- Requirements for returning safely to flight; and
- Technical excellence.

This summary addresses NASA's key actions in response to these three areas.

Changing the NASA culture

The CAIB found that NASA's history and culture contributed as much to the *Columbia* accident as any technical failure. NASA will pursue an in-depth assessment to identify and define areas where we can improve our culture and take aggressive corrective action. In order to do this, we will

- Create a culture that values effective communication and empowers and encourages employee ownership over work processes.
- Assess the existing safety organization and culture to correct practices detrimental to safety.
- Increase our focus on the human element of change management and organizational development.

- Remove barriers to effective communication and the expression of dissenting views.
- Identify and reinforce elements of the NASA culture that support safety and mission success.
- Ensure that existing procedures are complete, accurate, fully understood, and followed.
- Create a robust system that institutionalizes checks and balances to ensure the maintenance of our technical and safety standards.
- Work within the Agency to ensure that all facets of cultural and organizational change are continually communicated within the NASA team.

To strengthen engineering and safety support, NASA

- Is reassessing its entire safety and mission assurance leadership and structure, with particular focus on checks and balances, line authority, required resources, and funding sources for human space flight safety organizations.
- Is restructuring its engineering organization, with particular focus on independent oversight of technical work, enhanced technical standards, and independent technical authority for approval of flight anomalies.
- Has established a new NASA Engineering and Safety Center to provide augmented, independent technical expertise for engineering, safety, and mission assurance. The function of this new Center and its relationship with NASA's programs will evolve over time as we progress with our implementation of the CAIB recommendations.
- Is returning to a model that provides NASA subsystem engineers with the ability to strengthen government oversight of Space Shuttle contractors.
- Will ensure that Space Shuttle flight schedules are consistent with available resources and acceptable safety risk.

To improve communication and decision making, NASA will

- Ensure that we focus first on safety and then on all other mission objectives.
- Actively encourage people to express dissenting views, even if they do not have the supporting data on hand, and create alternative organizational avenues for the expression of those views.
- Revise the Mission Management Team structure and processes to enhance its ability to assess risk and to improve communication across all levels and organizations.

To strengthen the Space Shuttle Program management organization, NASA has

- Increased the responsibility and authority of the Space Shuttle Systems Integration office in order to ensure effective coordination among the diverse Space Shuttle elements. Staffing for the Office will also be expanded.
- Established a Deputy Space Shuttle Program Manager to provide technical and operational support to the Manager.
- Created a Flight Operations and Integration Office to integrate all customer, payload, and cargo flight requirements.

To continue to manage the Space Shuttle as a developmental vehicle, NASA will

- Be cognizant of the risks of using it in an operational mission, and manage accordingly, by strengthening our focus on anticipating, understanding, and mitigating risk.
- Perform more testing on Space Shuttle hardware rather than relying only on computer-based analysis and extrapolated experience to reduce risk. For example, NASA is conducting extensive foam impact tests on the Space Shuttle wing.
- Address aging issues through the Space Shuttle Service Life Extension Program, including midlife re-certification.

To enhance our benchmarking with other high-risk organizations, NASA is

- Completing a NASA/Navy benchmarking exchange focusing on safety and mission assurance policies, processes, accountability, and control measures to identify practices that can be applied to NASA programs.
- Collaborating with additional high-risk industries such as nuclear power plants, chemical production facilities, military flight test organizations, and oil-drilling operations to identify and incorporate best practices.

To expand technical and cultural training for Mission Managers, NASA will

- Exercise the Mission Management Team with realistic in-flight crisis simulations. These simulations will bring together the flight crew, flight control team, engineering staff, and Mission Management Team, and other appropriate personnel to improve communication and to teach better problem recognition and reaction skills.
- Engage independent internal and external consultants to assess and make recommendations that will address the management, culture, and communications issues raised in the CAIB Report.
- Provide additional operational and decision-making training for mid- and senior-level program managers. Examples of such training include, Crew Resource Management training, a U.S. Navy course on the *Challenger* launch decision, a NASA decision-making class, and seminars by outside safety, management, communications, and culture consultants.

Returning safely to flight

The physical cause of the *Columbia* accident was insulation foam debris from the External Tank left bipod ramp striking the underside of the leading edge of the left wing, creating a breach that allowed superheated gases to enter and destroy the wing structure during entry. To address this problem, NASA will identify and eliminate critical ascent debris and will implement other significant risk mitigation efforts to enhance safety.

Critical ascent debris

To eliminate critical ascent debris, NASA

- Is redesigning the External Tank bipod assembly to eliminate the large foam ramp and replace it with electric heaters to prevent ice formation.
- Will assess other potential sources of critical ascent debris and eliminate them. NASA is already pursuing a comprehensive testing program to understand the root cause of foam shedding and develop alternative design solutions to reduce the debris loss potential.
- Will conduct tests and analyses to ensure that the Shuttle can withstand potential strikes from noncritical ascent debris.

Additional risk mitigation

Beyond the fundamental task of eliminating critical debris, NASA is looking deeper into the Shuttle system to more fully understand and anticipate other sources of risk to safe flight. Specifically, we are evaluating known potential deficiencies in the aging Shuttle, and are improving our ability to perform on-orbit assessments of the Shuttle's condition and respond to Shuttle damage.

Assessing Space Shuttle condition

NASA uses imagery and other data to identify unexpected debris during launch and to provide general engineering information during missions. A basic premise of test flight is a comprehensive visual record of vehicle performance to detect anomalies. Because of a renewed understanding that the Space Shuttle will always be a developmental vehicle, we will enhance our ability to gather operational data about the Space Shuttle.

To improve our ability to assess vehicle condition and operation, NASA will

- Implement a suite of imagery and inspection capabilities to ensure that any damage to the Shuttle is identified as soon as practicable.
- Use this enhanced imagery to improve our ability to observe, understand, and fix deficiencies in all parts of the Space Shuttle. Imagery may include
  - ground-, aircraft-, and ship-based ascent imagery
  - new cameras on the External Tank and Solid Rocket Boosters
  - improved Orbiter and crew handheld cameras for viewing the separating External Tank
  - cameras and sensors on the International Space Station and Space Shuttle robotic arms
  - International Space Station crew inspection during Orbiter approach and docking
- Establish procedures to obtain data from other appropriate national assets.
- For the time being we will launch the Space Shuttle missions in daylight conditions to maximize imagery capability until we fully understand and can mitigate the risk that ascent debris poses to the Shuttle.

Responding to Orbiter damage

If the extent of the *Columbia* damage had been detected during launch or on orbit, NASA would have done everything possible to rescue the crew. In the future, we will fly with plans, procedures, and equipment in place that will offer a greater range of options for responding to on-orbit problems.

To provide the capability for Thermal Protection System on-orbit repairs, NASA is

- Developing materials and procedures for repairing Thermal Protection System tile and Reinforced Carbon-Carbon panels in flight. Thermal Protection System repair is feasible but technically challenging. The effort to develop these materials and procedures is receiving the full support of the Agency's resources, augmented by experts from industry, academia, and other U.S. Government agencies.

To enhance the safety of our crew, NASA

- Is evaluating a contingency concept for an emergency procedure that will allow stranded Shuttle crew to remain on the International Space Station for extended periods until they can safely return to Earth.
- Will apply the lessons learned from *Columbia* on crew survivability to future human-rated flight vehicles. We will continue to assess the implications of these lessons for possible enhancements to the Space Shuttle.

Enhancing technical excellence

The CAIB and NASA have looked beyond the immediate causes of the *Columbia* tragedy to proactively identify both related and unrelated deficiencies.

To improve the ability of the Shuttle to withstand minor damage, NASA will

- Develop a detailed database of the Shuttle's Thermal Protection System, including Reinforced Carbon-Carbon and tiles, using advanced nondestructive inspection and additional destructive testing and evaluations.
- Enhance our understanding of the Reinforced Carbon-Carbon operational life and aging process.
- Assess potential Thermal Protection System improvements for Orbiter hardening.

To improve our vehicle processing, NASA

- And our contractors are returning to appropriate standards for defining, identifying, and eliminating foreign object debris during vehicle maintenance activities to ensure a thorough and stringent debris prevention program.
- Has begun a review of existing Government Mandatory Inspection Points. The review will include an assessment of potential improvements, including development of a system for adding or deleting Government Mandatory Inspection Points as required in the future.
- Will institute additional quality assurance methods and process controls, such as requiring at least two employees at all final closeouts and at External Tank manual foam applications.
- Will improve our ability to swiftly retrieve closeout photos to verify configurations of all critical subsystems in time-critical mission scenarios.
- Will establish a schedule to incorporate engineering changes that have accumulated since the Space Shuttle's original design into the current engineering drawings. This may be best accomplished by transitioning to a computer-aided drafting system, beginning with critical subsystems.

To safely extend the Space Shuttle's useful life, NASA

- Will develop a plan to recertify the Space Shuttle, as part of the Shuttle Service Life Extension.
- Is revalidating the operational environments (e.g., loads, vibration, acoustic, and thermal environment) used in the original certification.
- Will continue pursuing an aggressive and proactive wiring inspection, modification, and refurbishment program that takes full advantage of state-of-the-art technologies.
- Is establishing a prioritized process for identifying, approving, funding, and implementing technical and infrastructure improvements.

To address the public overflight risk, NASA will

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

To improve our risk analysis, NASA

- Is fully complying with the CAIB recommendation to improve our ability to predict damage from debris impacts. We are validating the Crater debris impact analysis model use for a broader range of scenarios. In addition, we are developing improved physics-based models to predict damage. Further, NASA is reviewing and validating all Space Shuttle Program engineering, flight design, and operational models for accuracy and adequate scope.
- Is reviewing its Space Shuttle hazard and failure mode effects analyses to identify unacknowledged risk and overly optimistic risk control assumptions. The result of this review will be a more accurate assessment of the probability and severity of potential failures and a clearer outline of controls required to limit risk to an acceptable level.
- Will improve the tools we use to identify and describe risk trends. As a part of this effort, NASA will improve data mining to identify problems and predict risk across Space Shuttle Program elements.

To improve our Certification of Flight Readiness, NASA is

- Conducting a thorough review of the Certification of Flight Readiness process at all levels to ensure rigorous compliance with all requirements prior to launch.
- Reviewing all standing waivers to Space Shuttle Program requirements to ensure that they are necessary and acceptable. Waivers will be retained only if the controls and engineering analysis associated with the risks are revalidated. This review will be completed prior to return to flight.

Next steps

The CAIB directed that some of its recommendations be implemented before we return to flight. Other actions are ongoing, longer-term efforts to improve our overall human space flight programs. We will continue to refine our plans and, in parallel, we will identify the budget required to implement them. NASA will not be able to determine the full spectrum of recommended return to flight hardware and process changes, and their associated cost, until we have fully assessed the selected options and completed some of the ongoing test activities.

Conclusion

The American people have stood with NASA during this time of loss. From all across the country, volunteers from all walks of life joined our efforts to recover *Columbia*. These individuals gave their time and energy to search an area the size of Rhode Island on foot and from the air. The people of Texas and Louisiana gave us their hospitality and support. We are deeply saddened that some of our searchers also gave their lives. The legacy of the brave Forest Service helicopter crew, Jules F. Mier, Jr., and Charles Krenek, who lost their lives during the search for *Columbia* debris will join that of the *Columbia*'s crew as we try to do justice to their memory and carry on the work for the nation and the world to which they devoted their lives.

All great journeys begin with a single step. With this initial implementation plan, we are beginning a new phase in our return to flight effort. Embracing the CAIB Report and all that it includes, we are already beginning the cultural change necessary to not only comply with the CAIB recommendations, but to go beyond them to anticipate and meet future challenges.

With this and subsequent iterations of the implementation plan, we take our next steps toward return to safe flight. To do this, we are strengthening our commitment to foster an organization and environment that encourages innovation and informed dissent. Above all, we will ensure that when we send humans into space, we understand the risks and provide a flight system that minimizes the risk as much as we can. Our ongoing challenge will be to sustain these cultural changes over time. Only with this sustained commitment, by NASA and by the nation, can we continue to expand human presence in space—not as an end in itself, but as a means to further the goals of exploration, research, and discovery.

The *Columbia* accident was caused by collective failures; by the same token, our return to flight must be a collective endeavor. Every person at NASA shares in the responsibility for creating, maintaining, and implementing the actions detailed in this report. Our ability to rise to the challenge of embracing, implementing, and perpetuating the changes described in our plan will ensure that we can fulfill the NASA mission—to understand and protect our home planet, to explore the Universe and search for life, and to inspire the next generation of explorers.