The Integrated Risk Acceptance Approach for Return To Flight

Presented to:
Stafford-Covey Return-to-Flight Task Group

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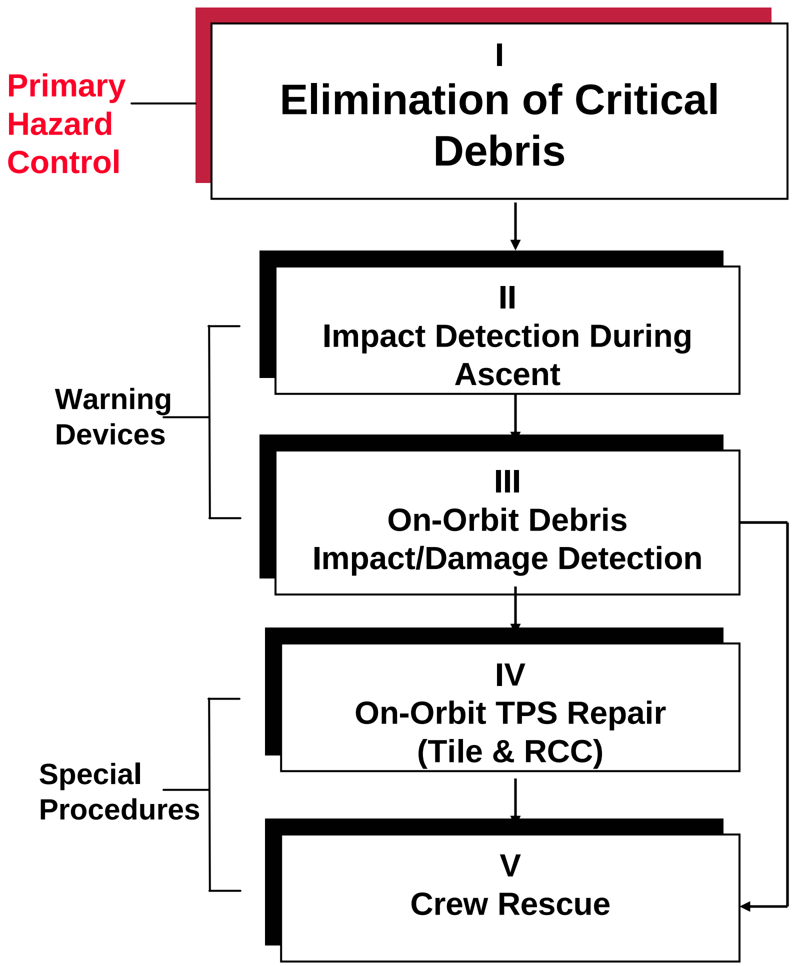
Risk Management Approach for Debris Elimination/Minimization

- Eliminate or minimize foam debris from the External Tank and other sources
- Use the traditional hazard reduction sequence to address debris
  - Design for Minimum Risk
  - Incorporate Safety Devices
  - Apply Warning Devices
  - Develop Special Procedures
- Identify and elevate residual risk for acceptance at the appropriate level of NASA Management commensurate with risk being accepted.



What NASA has Accomplished to Eliminate or Minimize Critical Debris Sources

DESIGN FOR MINIMUM RISK

- External Tank Design Changes
  - Bi-Pod Foam Ramp Elimination
  - LOX Feedline Bellows Ice Elimination/Reduction
  - PAL Ramp Verification Re-Validation/NDE
  - LH2 Intertank Flange Closeout Redesign

SAFETY DEVICES

- Orbiter Hardening
- Non-Destructive Evaluation
- Physics-Based Modeling
- Impact Tolerance Determination

WARNING DEVICES

- Improved Imagery (Ground, Airborne, On-Vehicle, On-Orbit Photography, Digital Downlink/Processing)
- Wing Leading Edge Sensor System
- On-Orbit Inspection (OBSS with LDRI and LCS)

SPECIAL PROCEDURES

- On-Orbit Repair of RCC/Tile
- Contingency Shuttle Crew Support

NASA will have an unprecedented understanding of the Orbiter TPS condition before committing to entry with the crew

Flight Rationale Summary

- Since the loss of Columbia, we have undertaken a far reaching program not only to understand and eliminate the source of the Columbia accident, but also to understand the other vulnerabilities in the Space Shuttle system, and to improve our overall approach to safety and mission assurance.
  - We understand the cause of foam and ice loss from the ET and have reduced/eliminated it through process changes and redesign efforts.
  - We understand the mechanism by which ascent debris is transported to the Orbiter and have used this understanding to focus on areas which are particularly vulnerable.
  - We understand the capability of the Orbiter to withstand damage. We have hardened the Orbiter against debris in some areas.
  - We have an unprecedented ascent imagery and on-orbit inspection capability that will allow us to detect and respond to critical damage to the Orbiter TPS.
  - We have developed limited on-orbit repair capabilities and a last-resort contingency safe haven capability.

Flight Rationale Summary

- When we return to flight, we will have the most comprehensive understanding of the Space Shuttle system since the Program's inception.
- We have reorganized and reinvigorated the safety and systems engineering functions within the SSP.
- The MMT has been revamped to be a highly focused, well trained, critical decision-making body.
- NASA has created a robust, independent safety function with the NESC, ITA, and institutional S&MA.
- We have not eliminated the risk inherent in human space flight. We have done the hard work necessary to accurately characterize the risk, and reduced it to an acceptable level.

Residual Risks Associated with Return To Flight

Residual Risk

- **Debris allowable requirements for the ET exceed Orbiter TPS damage tolerance.**

Risk Acceptance Rationale

- **Acceptability pending results of ongoing probabilistic sensitivity analysis.**
  - **Statistical confidence will be based on Monte Carlo simulations using combined environmental influences and associated distributions of debris liberation and trajectories.**
- **Orbiter TPS damage tolerance based on impact tests severity varies on impact angle, debris mass, debris shape, and velocity at impact; not all are impacts are catastrophic.**
- **Risk acceptance also based on impact/damage detection capabilities through imagery, on-orbit inspection, and limited TPS repair capabilities.**
- **In the most dire of situations, CSCS will be declared and LON rescue mission will be undertaken.**

Residual Risks Associated with Return To Flight

Residual Risk

- **There is a high degree of statistical uncertainty due to the small sample size associated with approach taken to determine the population, size, and predominant locations of debris liberation from the External Tank.**

Risk Acceptance Rationale

- **Dissection of ET-94 foam used to characterize re-certified/as-sprayed and determine if foam application process capability was sufficient to meet debris allowable requirements.**
- **Process capability applied in analytical model and used for verification; conservative limits applied for number and size of defects.**
- **We acknowledge that the number of data points is insufficient to define process capability through statistical means; however, no significant differences noted in similar materials and applications. Similar data were combined to increase confidence.**
- **Final demonstration can only be made in flight with combined effects of ascent environment.**

Residual Risks Associated with Return To Flight

Residual Risk	**Risk Acceptance Rationale**
• **Cryogenic behavior acceptance criteria were established using a limited number of test data points for ET foam. There is insufficient data to characterize the mechanism by which a void will cause TPS failure under cryo-ingestion/cryo-pumping conditions.**	• **A large amount of empirical data gathered through tests that supports the established defect acceptance criteria with high confidence. This testing identified sensitivities to key parameters and was conducted at conditions that promoted divoting.**
• **Causes of knit-line cracks, a possible contributor to foam loss, have not been characterized by definitive test data.**	• **Discipline in spray technique has been stressed in operator training to preclude errant conditions leading to knit line cracks.** • **Additional controls have been added including Quality Assurance verification and post-spray video review to ensure that errant conditions did not occur during the spray operation.**

Residual Risks Associated with Return To Flight

Residual Risk

- **Foam spray process sensitivities are not fully understood.**

Risk Acceptance Rationale

- **An extensive amount of work has been accomplished to understand foam behavior. Process controls have been implemented to maintain desired performance, including:**
  - **Minimum of four verification sprays for each application.**
  - **Production witness panels using high-fidelity mockups used to train technicians prior to flight hardware sprays. Validation hardware & witness panels inspected, tested, and dissected for acceptance.**
  - **Verification processing windows limited to well-understood parameters.**
  - **Spray schedules, acceptance criteria, quality and data requirements established for all processes.**

Residual Risks Associated with Return To Flight

Residual Risk

- **There are further limitations in the External Tank verification program associated with compliance to the requirements for Thermal Protection System (TPS) allowable debris.**

Risk Acceptance Rationale

- **Descriptions of these limitations and their implications are provided in NSTS 60555, *Verification Limitations for the External Tank Thermal Protection System*, to complement efforts by the Space Shuttle Program to assess the risk to flight safety. The effects of these issues are decreased confidence in the verification results and increased likelihood that ET TPS debris allowable requirements will be violated. However, NSTS 60555 delineates the residual risk acceptance rationale and has been accepted by the Space Shuttle Program.**

Residual Risks Associated with Return To Flight

Residual Risk

- **Not all vulnerable areas of the Orbiter will be hardened prior to Return To Flight.**
  - **Areas that will not be hardened before Return To Flight but are in work include wing leading edge front spar "sneak flow" path protection (RCC panels #1-#4 and #14-#22) and main landing gear door enhanced thermal barrier redesign.**

Risk Acceptance Rationale

- **Modifications made include:**
  - **Thicker outer pane windows installed in positions #1 and #6.**
  - **Forward RCS carrier panel bonded stud elimination/redesign.**
  - **Wing leading edge front spar "sneak flow" path protection and horsecollar gap filler redesign for RCC panels #5-#13.**
  - **Main landing gear door corner void reduction.**
- **Imagery and inspection capabilities will provide knowledge of the Orbiter TPS condition prior to committing to re-entry.**
- **Areas identified with critical damage that can not support re-entry will be considered for repair.**
- **In the most dire of situations, CSCS will be declared and LON rescue mission will be undertaken.**

Residual Risks Associated with Return To Flight

Residual Risk

- **Individual imagery assets alone are not adequate to detect critical damage, so there is limited redundancy in the inspection system.**

Risk Acceptance Rationale

- **Inspection methods and warning devices are not redundant, but each provides a different part of the puzzle, offering overlapping information of the Orbiter's TPS condition.**
- **We can accept failure of one or more warning device/inspection method and have the confidence that we will be able to characterize potential debris liberation and possible damage to Orbiter TPS.**
- **We accept this approach as a reasonable risk.**

Residual Risks Associated with Return To Flight

Residual Risk

- **The STS-114 mission will be conducted with limited, uncertified TPS repair capabilities that will be designated as available at the Flight Readiness Review.**

Risk Acceptance Rationale

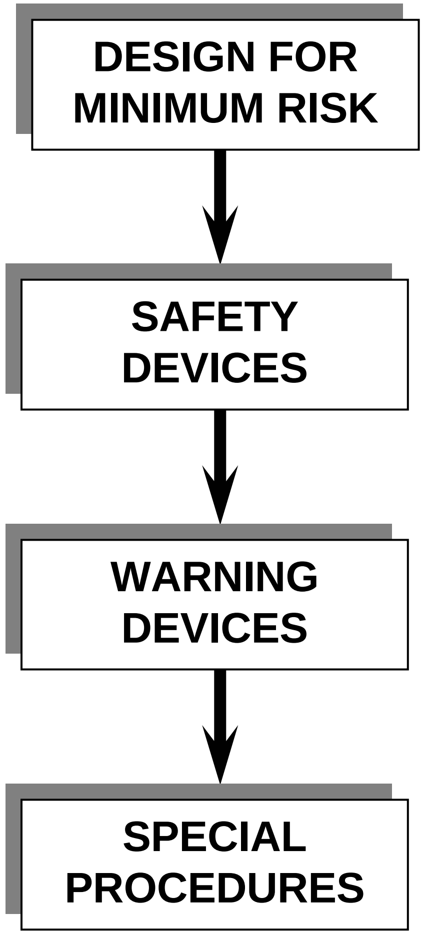
- **NASA has put forth our best effort in developing practicable methods of TPS repair techniques.**
- **We plan to take five TPS repair capabilities on STS-114 and demonstrate two of the five.**
- **Although none of our repair capabilities are certified to the degree desired, each repair technique has been demonstrated to provide some level of protection against a simulated entry environment.**
- **Taking all available repair capabilities to orbit is a prudent step in the unlikely event that we have failed to properly understand the debris environment.**
- **NASA considers this approach to be reasonable and acceptable.**

Residual Risks Associated with Return To Flight

Residual Risk	**Risk Acceptance Rationale**
• **There is a finite amount of physical test results available to validate the suite of analytical tools developed to model foam release mechanisms, debris transport mechanisms, TPS impact tolerance, TPS repair decision support, and TPS repair capability.**	• **All physics-based models have been peer reviewed and verified appropriate for their specific application. NASA understands and accepts the limitations of existing physics-based models for use on STS-114.**
• **Testing performed to date to support and validate analytical models may not be of sufficient number and repetitions to provide statistical confidence.**	• **Until sufficient number of repetitions in test results can be achieved, sound engineering judgment will dominate the decision process with models in a support role. NASA believes this approach to be reasonable and prudent, and accepts the associated residual risk.**

BACK-UP

Traditional Hazard Reduction Protocol Used



The major goal throughout the design phase shall be to ensure inherent safety through the selection of appropriate design features as fail operational/fail safe combinations and appropriate safety factors. Hazards shall be eliminated by design where possible. Damage control, containment and isolation of potential hazards shall be included in design considerations.

Known hazards which cannot be eliminated through design selection shall be reduced to an acceptable level through the use of appropriate safety devices as part of the system, subsystem, or equipment.

Where it is not possible to preclude the existence or occurrence of a known hazard, devices shall be employed for the timely detection of the condition and the generation of an adequate warning signal. Warning signals and their application shall be designed to minimize the probability of wrong signals or of improper personnel reaction to the signal.

Where it is not possible to reduce the magnitude of existing or potential hazard through design, or the use of safety and warning devices, special procedures shall be developed to counter hazardous conditions for enhancement of ground and flight crew safety. Precautionary notations shall be standardized.

We Have Had Significant Accomplishments

- We have expanded our knowledge base to include a deeper understanding of the debris generation mechanisms in all Space Shuttle elements and the associated debris transport models, and, through tests and analyses, the ability of the Orbiter to withstand debris impact.
  - We gained this understanding in part by dissecting External Tank foam to verify void distribution, through divot testing to validate the divot generation models, and through aero-thermal wind tunnel tests to validate ascent heating regimes that lead to foam liberation.
  - We conducted wind tunnel tests to measure transport speeds to validate Shuttle flow velocities and pressure distributions and gain an improved understanding of the flow fields around the vehicle and define debris transport mechanisms.
  - We analyzed liberated foam divots in wind tunnels to define divot aerodynamics.
  - We determined Orbiter thermal protection system impact tolerance through coupon material tests to verify material properties.
  - We conducted full-scale foam and reinforced carbon-carbon element impact tests with foam to determine material response capabilities and impact tolerances, as well as to validate impact models.
  - We conducted ice impact testing to demonstrate the impact tolerance of reinforced carbon-carbon elements.

We Have Had Significant Accomplishments

- We re-trained our External Tank manufacturing workforce and redesigned the areas that have historically produced large foam debris, including the bipod ramps and liquid hydrogen intertank flange.
- We redesigned the Solid Rocket Booster to External Tank bolt catcher assembly and reassessed the booster separation motors for ignition characteristics and as a debris source.
- We initiated an Orbiter hardening program by adding thicker windows, installing thermal insulation blankets behind the wing leading edge, eliminating corner voids in the main landing gear doors, and redesigning the forward reaction control system carrier panel. We introduced new thruster covers to reduce the potential for release of debris at high speeds. We inspected all reinforced carbon-carbon elements and attach hardware at the vendor to verify integrity. We also inspected and replaced as necessary, rudder speed-brake and body flap actuators, flex hoses, wiring, and cold plates.

We Have Had Significant Accomplishments

- We will launch with new lighting requirements for at least the first two flights that allow the ground cameras to record the integrated vehicle in great detail through Solid Rocket Booster separation.
- We will track the vehicle with debris-identification radar from three sides, using two ground-based radars and one ship-based radar.
- We will have visual and near-infrared cameras on two WB-57 aircraft to image the vehicle through Solid Rocket Booster separation.
- We will see Solid Rocket Booster separation from cameras mounted on the Solid Rocket Boosters and the separation of the External Tank from a camera that will record and downlink images of the vehicle from lift-off on.
- We will image the External Tank after separation under precise lighting conditions using digital cameras in the umbilical well; images will be downlinked in near-real time for evaluation.

We Have Had Significant Accomplishments

- ❖ We will employ a new procedure for crew photography and arm the crew with new digital cameras to take more detailed images of the External Tank after separation though the overhead windows.
- ❖ We have the capability to acquire and downlink data from new wing leading edge acoustic and temperature sensors to determine if there were impacts during ascent.
- ❖ We will use our new Orbiter Boom Sensor System for the first time on flight day two to take detailed images of the reinforced carbon-carbon wing leading edge and nose cone surfaces with a laser and camera. We have developed backups to the boom sensor system including redundant laser and camera, new digital cameras to be used by space-walking astronauts, and made modifications to the space walk suits and the mini-back pack used for self rescue by a space walking astronaut.

We Have Had Significant Accomplishments

- We have developed a procedure that will be used to pitch the Orbiter around as it approaches the International Space Station, to present the bottom of the Orbiter to the station crew so they can take pictures of the thermal protection system tile, blankets, and reinforced carbon-carbon elements with new cameras that were flown to the station on a recent Progress vehicle.
- If we find damage, we have developed a real-time planning process and procedures to use the boom sensors to conduct focused inspections of potential critical damage sites identified through imagery capabilities described above. Data from focused inspections will feed sophisticated new modeling tools that will assess criticality of damaged tile and reinforced carbon-carbon elements and determine, in part, the need for repairs. Engineering judgment will also play an important part in formulating repair recommendations.

We Have Had Significant Accomplishments

- We will take five different thermal protection system repair capabilities on the Return To Flight mission; two for reinforced carbon-carbon and three for tile. Two lines of defense for thermal protection system repair, the emittance wash and the NOAX crack repair capabilities will be tested during a space walk on STS-114.
- If repairs are needed, we have developed four different procedures to access the repair site: off the Shuttle robotic arm; off the boom attached to the Shuttle robotic arm; off the International Space Station robotic arm; and with the Orbiter Repair Maneuver that uses both the Station and Shuttle arms.
- We have planned for crew rescue so that if a threat is identified that would preclude safe re-entry of the vehicle, we know our capability to maintain the Shuttle crew on station and what steps are needed to attempt a rescue mission. We have also developed new seats and crew survival equipment to support a contingency rescue mission.

We Have Had Significant Accomplishments

- We formed and staffed the NASA Engineering and Safety Center to actively assist with technical issues and provide a second, independent set of eyes and analyses.
- We chartered the Independent Technical Authority with appropriate technical warrant holders who are key members of daily technical deliberative processes.
- We reinvigorated the Safety and Mission Assurance organizations and staffs at Kennedy, Johnson, Marshall and Stennis Space Centers, making them independent assessors in the quest for achieving higher levels of safe, reliable operations.
- We reconstituted and reinvigorated the Systems Engineering and Integration Office, placing it in the forefront of the collaborative engineering effort for Return To Flight.

We Have Had Significant Accomplishments

- We have completely revised the Integrated Hazard Analysis Reports to make them more comprehensive in scope, technically accurate, and up to date. All of these Integrated Hazard Analysis Reports will be reviewed and approved by the Space Shuttle Program Manager prior to launch.
- Finally, we have hired additional engineers in critical areas. A new Mission Evaluation Room was built to allow engineering and safety staffs to do their jobs more effectively and collaboratively. The Mission Management Team was totally revamped, with certification of members and with outside participation from five different NASA Centers, as well as the NASA Engineering and Safety Center, the Independent Technical Authority, Safety and Mission Assurance, and the Systems Engineering and Integration Office organizations.