2 RELATIONSHIPS AMONG THE RECOMMENDATIONS

A large majority of the CAIB return to flight recommendations rely on the results of other recommendations and should be placed in context to properly evaluate and appreciate the volume of work accomplished by NASA over the last two years. In many instances, the Task Group could not easily assess one recommendation without considering others. With few exceptions (R4.2-5; KSC Foreign Object Debris, and R4.2-3, Two Person Closeout Inspections), all of the technical and operational recommendations were closely linked via their relationship to the overall risk acceptance rationale used by NASA. In addition, the Agency's response to the management recommendations influenced how the other recommendations were ultimately implemented.

There was initial consideration within the Task Group of combining the assessments of several recommendations in this report, but ultimately it was believed that each assessment should stand alone – to the extent possible – to make it easier for the reader to locate the particular recommendation. However, it was also felt that it was necessary to explain the relationships among the recommendations.

A similar quandary apparently confronted NASA. An early attempt within the NASA Safety and Mission Assurance community to integrate the intent of the recommendations into a whole came in the form of the Thermal Protection System Risk Reduction Framework, presented below. Using this framework, a larger picture emerges of the NASA implementation of the CAIB return-to-flight recommendations.

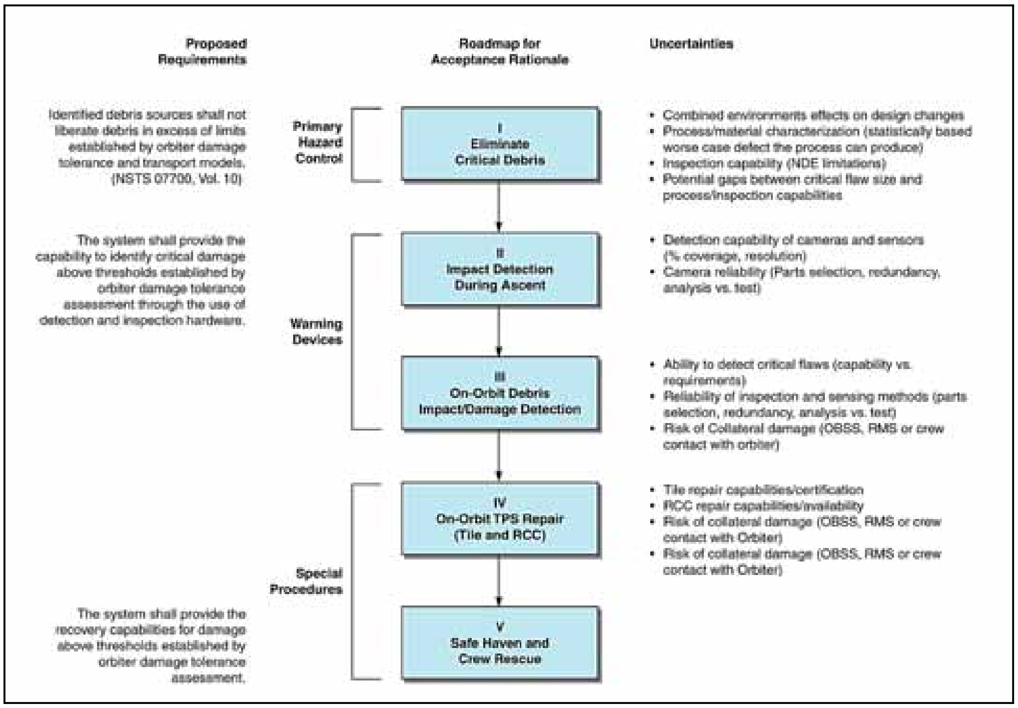
2.1 Thermal Protection System Risk Reduction Framework

The most important technical issue to be resolved before returning to flight was preventing ascent debris from causing critical damage to the Orbiter Thermal Protection System. The Space Shuttle Program Safety and Mission Assurance Manager described a proposed framework for thermal protection system risk reduction to the RTF TG at the April 2004 plenary. This framework, starting with primary hazard control, further delineated appropriate warning devices and special procedures to mitigate the risk of the primary hazard control not being completely satisfied, and directly encompassed several of the CAIB return-to-flight recommendations. The Task Group found this useful for putting various recommendations in context with one another.

The primary hazard control, or the first step in the roadmap, was to "Eliminate Critical Debris." This was a combination of subparts: understand and improve the current ability of the Orbiter to withstand debris impacts (R3.3-2), ensure that the reinforced carbon-carbon panels currently in use were not already damaged (R3.3-1), and attempt to eliminate ascent debris (especially from the External Tank, R3.2-1, and SRB bolt catchers, R4.2-1).

Warning devices encompassed the second and third steps in the roadmap. The second step, "Impact Detection During Ascent," covered ground-based imagery (R3.4-1), high-resolution imagery of the ET (R3.4-2), observation cameras mounted on the ET and SRBs (a component of R3.4-3), data from National assets (R6.3-2), and data from the wing leading edge impact detection system (a component of the inspection portion of R6.4-1). Step III, "On-Orbit Debris Impact/Damage Detection," dealt with the Orbiter Boom Sensor System (OBSS) and R-Bar Pitch Maneuver imagery taken from the International Space Station that are part of the inspection portion of R6.4-1 and which provide the high-resolution capability to meet R3.4-3.

An implicit step in this roadmap was the integration of data from the warning devices into an assessment of any damage sustained by the Orbiter Thermal Protection System during the mission. The combination of that data with the knowledge of the capability of the Orbiter to enter with damage (the second part of R3.3-2) and closeout photography depicting the last known state of the Orbiter (R10.3-1), results in a determination of whether repair (the other part of R6.4-1) needs to be initiated. Additionally, test and analysis provide the rationale to continue with entry or invoke the safe haven offered by Contingency Shuttle Crew Support (CSCS – SSP-3). The integration of this data has been the primary focus of the Task Group's Integrated Vehicle Assessment Sub-Panel (IVASP) and is further addressed in Section 2.2. At the Task Group's urging, MMT simulations (R6.3-1) and component simulations (R3.3-2 and R6.4-1) exercised the resulting process. However, the Task Group cautions that limitations in these inspection capabilities may still allow damage to go undetected.



The last two steps, which hopefully will never need to be exercised during a mission, are called "Special Procedures." Step IV, "On-Orbit TPS Repair (Tile and RCC)," is addressed in the repair portion of R6.4-1. The final step of the roadmap, "Safe Haven and Crew Rescue," is the focus of the "raising the bar" action for CSCS (SSP-3) that the Space Shuttle Program assigned to itself, and is not a direct response to a CAIB recommendation.

On the management side, expanding the role of the Space Shuttle Integration Office to address the entire Space Shuttle system (R7.5-3) enabled the new Systems Engineering and Integration Office (SEIO) to lead the effort to understand the effects of debris, to assess the remaining risk due to critical debris, and to integrate the in-flight TPS assessment activities. Many of the efforts in the paragraphs above entail development activities, and therefore carry the possibility that some requirements may not be met and waivers will need to be processed. Restoring specific engineering technical authority, independent of programmatic decision-making (R7.5-1) and increasing the authority, independence, and capability of the Safety and Mission Assurance (SMA) organizations (R7.5-2) provide independent voices in the waiver and resulting risk acceptance deliberations that the CAIB felt were missing at the time of the *Columbia* accident (R9.1-1).

Clearly, the more thoroughly critical debris can be eliminated (via a combination of reducing debris from the tank and increasing the ability of the Orbiter to withstand impacts), the less important the repair capability (with its attendant prerequisite ability to detect damage which needs to be repaired) or the rescue capability becomes. The more confidence in the detection and repair capabilities there is, the less the need for a crew safe haven and rescue function exists. The crew rescue capability is only a last resort (no matter the confidence one has in it) because in this case, the crew is saved; however, the damaged Orbiter is not salvaged. In addition, invoking CSCS would have significant impacts on the ISS, including the possible need to evacuate the station.

All of the steps in the roadmap have remaining uncertainties associated with them (see the column on the right of the diagram). There still exists a possibility that the Orbiter could sustain critical damage to the TPS. Limited actions were taken to harden the Orbiter, and there is a potential that debris from the External Tank could again critically damage an Orbiter during ascent. If such damage occurs, there is some risk that it could go undetected, not be repairable, or that a rescue mission could not be launched in time. Probabilistic analysis was used to quantify the residual risk of critical damage to the Orbiter Thermal Protection System from debris and is discussed in Section 3.3 as part of R3.3-2. Other risks are captured in the Integrated Hazard Reports.

NASA acknowledges that the elimination of all critical debris is not attainable; therefore the Agency has analyzed and formally accepted the remaining risk as a condition for the return to flight.

2.1.1 Summary

Many within the RTF TG were encouraged with this proposed “top-down” approach for hazard reduction. Similarly, it would have been beneficial if NASA had performed a top-down requirements flow-down that recognized the relationship between seemingly disconnected system elements with cross-cutting functional connectivity. Some members of the Task Group expressed an interest in seeing this implementation technique applied to all items in the *NASA Implementation Plan*, but no evidence of this approach was found by the Task Group. The failure to accomplish these tasks may ultimately result in unintended consequences from a lack of integration between elements.

The basic outline of the roadmap presented at the April 2004 plenary was eventually incorporated into a Headquarters document, *The Integrated Risk Acceptance Approach For Return To Flight*, intended to define the overall rationale for STS-114. The Task Group notes, however, this document has not been formalized – it has no author, no document number, no approval page, apparently no configuration management – and does not directly correlate to any program requirements. Nevertheless, progress has been made in incorporating risk reduction as part of various program, element, and project activities.

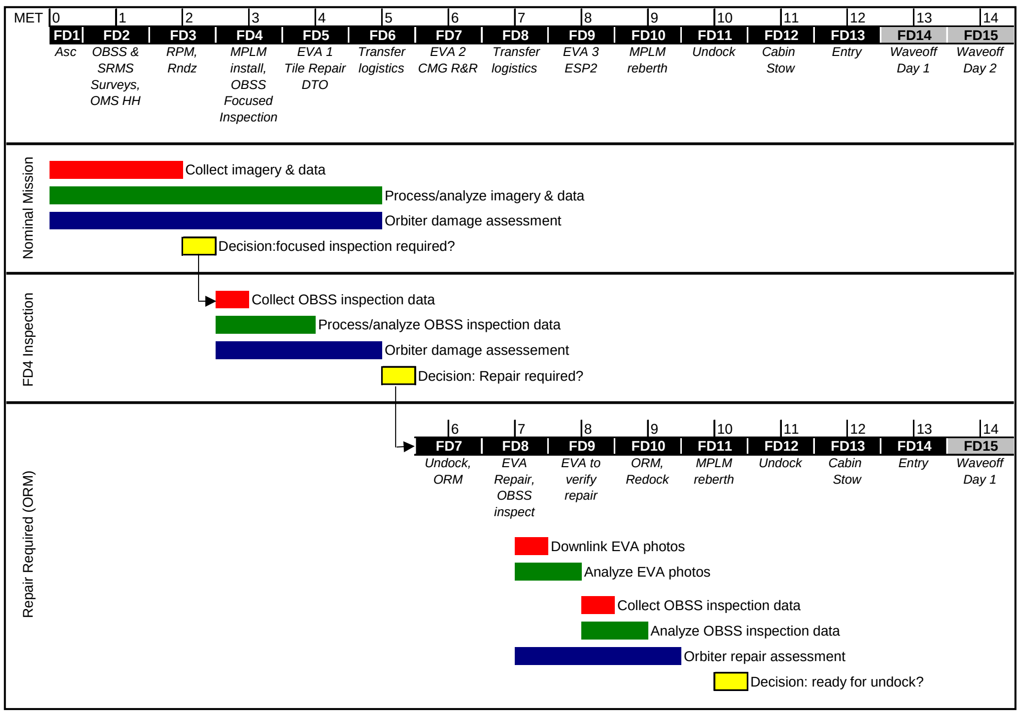
2.2 Integrated Vehicle Assessment

The RTF TG established the Integrated Vehicle Assessment Sub-Panel (IVASP) to combine insights from the Operations, Technical, and Management Panels in order to assess NASA’s ability to perform an integrated external damage assessment of the Orbiter based on a variety of data sources in direct support of real-time decision-making for Space Shuttle operations.

2.2.1 The NASA Response

As part of their return to flight effort, NASA developed a Orbiter Thermal Protection System readiness determination concept. This is documented in NSTS 60540, *STS-114 Operations Integration Plan for Thermal Protection System Assessment*, baselined April 12, 2005. This document states its intended purpose as, “This Operations Integration Plan (OIP) is the agreement on the responsibilities and tasks which directly relate to the integration activities associated with the successful system engineering, integration, and verification of the Space Shuttle return to flight activities associated with the assessment of the TPS. These operations are intended to provide the processes for transforming the data from the TPS assessment systems into information that can be used by Mission Management to make a timely TPS entry readiness, repair, or safe haven determination. This document constitutes an agreement on the part of participating organizations concerning products and tasks described."

The OIP is the response to Program Requirements Control Board (PRCB) Directive S064005, Action 14-1, to develop an integrated operations concept for ascent film and video, Orbiter umbilical well cameras, Orbiter Boom Sensor System inspection, wing leading-edge instrumentation, and external resources. The document also includes the plan for integration of pad walk down debris reports, ascent radar, Solid Rocket Booster recovery reports, International Space Station photography during the R-bar Pitch Maneuver, and debris transport analysis. In addition, the OIP includes an Annex, *Orbiter Damage Assessment Process*, that documents the damage assessment process, and the decision timeline required to support a safe entry assessment. The document focuses specifically on a description of the operations, the work and analysis to be performed, process dependencies, process flows, process responsibilities, and the verification requirements from an integrated perspective.



NASA timeline to collect, process and assess ascent and on-orbit data to determine the state of the Orbiter Thermal Protection System during a mission.

The OIP was developed based on the assets baselined for STS-114 with a daylight launch constraint; however, many of the processes outlined in this document are generic in nature and could apply to any Space Shuttle mission. Nevertheless, due to the evolutionary nature of the specific complement of assets, it was necessary to address the specific STS-114 configuration for the baseline release of the OIP. It is currently NASA's intent to update the document for future missions as the asset configurations and timelines required to support decision-making change, as well as to capture changes to the process deemed necessary to better support decision-making.

2.2.2 RTF TG Assessment

The Task Group commends the OIP and Damage Assessment Annex developers. Beginning from scratch, they have evolved a process that holds the promise of integrating a variety of new and disparate types of data into information that can support complex decision-making during flight. To do this, the developers had to work across NASA boundaries to identify the best organization to be responsible for each data source. They had to secure commitments from these organizations to produce data analysis reports on a specified timeline and to share those reports through the OIP. They have also identified and established new positions of authority required to set priorities on data collection and analysis to meet emerging real-time needs. They have conducted an aggressive training plan to exercise each component of the assessment process as well as the MMT use of the information. Finally, they fully documented the process so that it can be evolved as data sources change, studied by new participants in the process, and evaluated by outside observers.

The Task Group recognizes that the OIP and Damage Assessment Annex will continue to mature through STS-114 and, hopefully, beyond. NASA needs an ability to manage risk during flight, and these two documents represent a significant step in that direction. The CAIB recommendations identified specific data necessary to better understand the risk to the Orbiter of a debris impact. The Operations Integration Plan was developed to integrate the data from the new data sources developed for return-to flight and the Damage Assessment Annex was developed to clearly define how those data would be interpreted. We see the Space Shuttle Program's experience in these development initiatives as having potential that goes beyond the specific Thermal Protection System assessment sources developed for STS-114. It represents an approach that pulls information from across NASA boundaries into a consolidated, integrated "whole." There will likely be other anomalous situations during flight where such an approach could help the decision-makers assess and manage risk.

2.2.3 RTF TG Observations

During its assessment of the OIP, the Task Group had several observations.

2.2.3.1 <u>OIP/Damage Assessment Annex Development and Documentation</u>

NASA should continue to support and resource the OIP and Damage Assessment Annex processes. Furthermore, their accomplishments should serve as a model for tackling other integration challenges that NASA faces.

The Space Shuttle Program published several draft versions of the STS-114 Operations Integration Plan, culminating in the baseline version on April 12, 2005. Beginning in December 2004, NASA conducted a series of component simulations (sims), designed to test specific pieces of the OIP, and mini-integration simulations, designed to test parts of the process that involve integration. As elements of the OIP matured, they were incorporated into MMT simulations. These led to MMT sim #12, conducted in March 2005 that specifically included a number of Orbiter Thermal Protection System incidents requiring assessment. The Space Shuttle Program conducted a component sim the week prior to this MMT and used the outputs of the component sim as inputs to the full-scale MMT sim.

The Space Shuttle Program also released a revised version of the Orbiter Damage Assessment Process Annex on March 1, in time to support MMT sim #12. The IVASP reviewed the first version of this Annex in December 2004. The current revision is more mature and includes a detailed description of the processes the program will use to take the data collected and integrated through the OIP and use it to actually assess the status of the Thermal Protection System. The Annex further includes frameworks for risk-versus-risk assessments for both tile and RCC damage and repair activities. This Annex should continue to be exercised in the component and mini-integration sims scheduled before flight. The Space Shuttle Program should update both the OIP and Annex before flight to incorporate the lessons they have learned from their work through the sims, as well as incorporate final decisions for STS-114 resulting from the Debris DVR, the Program DCR, the FRR, and model validation.

2.2.3.2 Structured Assessment during Flight

During flight, the information and understanding gained from the STS-114 experience will be invaluable for future mission data integration. The Operations Integration Plan and Damage Assessment Process Annex developers should put in place a structured process to capture records of the data collected and the processes used to integrate and assess it during flight. The results of a review of this information coupled with the experiences of the participants should form the basis for the post-STS-114 OIP/Annex revisions.

2.2.3.3 Critical Damage/Debris Size Definition

The Space Shuttle Program must continue to mature its critical damage and critical debris assessments and incorporate the results into the OIP and Annex. The results of these assessments determine the operation and processing of some of the key sensors, such as those on OBSS. This could change the timelines the OIP has developed to ensure the data will be available to support the damage assessment process and associated key decisions.

2.2.3.4 Camera Requirements Analysis

During MMT sim #12, the participants debated the significance of the loss of a suite of ground cameras. Some participants felt that the camera's "Criticality 3" status made clear that they were not a constraint to flight, while others felt that the loss would preclude collection of important mission-essential information. Before the launch of STS-114, the Task Group believes that the relative importance of each camera (as well as all STS-114 inspection and imagery capabilities) should be pre-determined, to the extent possible, so that there is a clearer basis for these decisions. The Task Group is not recommending that the criticality of these cameras be changed. Rather we believe that, with all the cameras and sensors now available to NASA, the implications of the loss of a particular sensor need to be clear as the trade-offs are debated. This is even more of a factor for STS-114 since one of its explicit objectives is to document the debris environment actually experienced.

Because many of the cameras are redundant and because data are available at different times, this determination requires analysis. We believe the OIP developers have the expertise to do this work and the OIP is the best place to document the results. The Task Group recognizes that, for some views, there are so many cameras that it would be extremely time-consuming to detail all the permutations. While we still believe the full analysis should be done and documented eventually, it would be prudent for the OIP developers to focus on those views where there is little or no redundancy so that the implications of the loss of one or more of those systems are clear in time for the launch of STS-114.

Additionally, resources must be made available to sustain the enhanced imagery capability that feeds the inspection and damage assessment for the remainder of the Space Shuttle Program. There are inherent risks in space flight and the ability to observe and analyze the state of the vehicle to a high degree of confidence will always be required. It is imperative that NASA accept the responsibility to protect this capability, to use it for all missions, and continue to evaluate methods to improve it within limits for the duration of the Space Shuttle Program and for future programs.

2.2.4 Summary

The OIP and its Damage Assessment Annex represent a significant step toward developing a process to integrate and assess a variety of important information from disparate sources. The Task Group commends NASA for its progress in this area and recommends that this work continue after STS-114. The Task Group further suggests that the development of the OIP and its Annex could serve as a model for other cross-NASA integration projects.