Applicability of CAIB Findings/Recommendations to HST Servicing

EXECUTIVE SUMMARY

The final planned HST Servicing Mission, SM4, will be at least as safe as shuttle flights to the International Space Station (ISS). If shuttle return-to-flight occurs prior to the full implementation of an autonomous inspection and repair capability, the overall risks during a flight to Hubble would be comparable to those associated with an ISS flight in which the shuttle failed to reach ISS. Ultimately, when an autonomous inspection and repair capability is implemented, a mission to Hubble will then be as safe as any mission to ISS. Thus, an HST flight requires few, if any, unique capabilities to ensure safe flight beyond those developed for flights to the ISS. NASA plans to provide a Shuttle rescue capability for all flights. The flexibility to schedule SM4 immediately prior to one of the ISS flights provides a ready capability to mount a rescue mission if needed. Risks of micrometeoroid and orbital debris damage to shuttle on ISS flights exceeds that on flights to HST, given the flexibility in the latter to place the shuttle in a protective orientation.

A) RESCUE OR REPAIR

The CAIB Report addresses the possibility of rescue or repair in section 6.4 “Possibility of Rescue or Repair.” In this section, recommendation R6.4-1 contains four specific components:

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 tile and Reinforced Carbon-Carbon, taking advantage of the additional capabilities available when near to or docked at the International Space Station.

Currently, testing and analyses of the thermal protection system (TPS) is underway to determine failure modes and associated on-orbit inspection criteria. NASA plans to define damage thresholds below which no repair is required as well as thresholds above which repair is deemed unfeasible. For return to flight (RTF), NASA plans to perform inspections via ISS and demonstrate concepts for inspections and repair. For the next flight, full inspection of the TPS will be accomplished using the ISS as support. Design and simulations are underway for autonomous inspection (separate from ISS) utilizing a boom extension to the Shuttle remote manipulator system (SRMS).[1]

The current NASA plan to satisfy CAIB Recommendation 6.4-1 (TPS inspection and repair capabilities) is to use a combination of an instrumented boom "carried" by the Shuttle Remote Manipulator System and inspection capabilities of the ISS crew to

[1] Covey, Richard O., Return to Flight Task Group Interim Report, January 20, 2004

inspect for damage to the thermal protection system (TPS), which includes the tiles and the reinforced carbon carbon (RCC) wing leading edge. This inspection would identify any TPS areas that require repair prior to reentry.[2]

Development activities associated with tile repair techniques are currently further along than RCC repair techniques. Because the RCC repair techniques are currently at a relatively low level of technology development (technology readiness level (TRL) 2 as defined by NASA standards), NASA anticipates that RCC repair will not be ready for the RTF mission. NASA is developing a Shuttle rescue flight concept in the event that the ISS becomes a “safe haven” for a Shuttle crew. The Shuttle rescue concept includes plans for a non-ISS orbit rescue capability. Both concepts appear feasible.[3]

For the first several flights to the ISS after the RTF mission, the repair techniques would be accomplished using the Space Station Remote Manipulator System (SSRMS) holding the Orbiter and the Shuttle RMS (SRMS)-with-boom to take the astronaut and repair tools to the area on the Orbiter needing repair. Inspection and repair techniques that are executed from the ISS will become increasingly complex as the assembly progresses and physical interferences become more challenging. Eventually, unique solutions for ISS implementations will have to be developed.

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

Before a non-station mission could be flown, the Shuttle program would have to develop an autonomous (free from Station) inspection and repair capability using just the SRMS and boom. This autonomous capability would maximize the use of repair kits, techniques and procedures that are in development for use on Station missions. According to the Return to Flight Task Group Interim Report, NASA plans to implement autonomous inspection and repair capability.[2] However, in the absence of an autonomous capability, the risks associated with a flight to a non-station orbit would be comparable to that for an ISS flight where the Shuttle fails to dock with the ISS.

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

The implementation plan to perform inspections early applies to all missions, independent of destination.

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[2] NASA PAO, NASA Response to Questions: 04-008, January 15, 2004
[3] Space Shuttle Customer and Flight Integration Office, Shuttle Crew Rescue Flight Concept Complete, presented to Shuttle Program Office on November 21, 2003
[2] NASA PAO, NASA Response to Questions: 04-008, January 15, 2004

4. 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.

Once the autonomous capability is implemented, the capability would exist to fly to non-Station orbits without requiring any unique inspection and repair capabilities.

B) MICROMETEOROID AND ORBITAL DEBRIS (MMOD)

The CAIB found that there was "little evidence that Columbia encountered either micrometeoroids or orbital debris on this flight." The CAIB also "found markedly different criteria for margins of micrometeoroid and orbital debris safety between the International Space Station and the Shuttle." The Board recommended:

R4.2-4 Require the Space Shuttle to be operated with the same degree of safety for micrometeoroid and orbital debris as the degree of safety calculated for the International Space Station. Change the micrometeoroid and orbital debris safety criteria from guidelines to requirements.

The odds of critical penetration due to MMOD for a typical Shuttle flight to the ISS of 11 days, 18 hours mission duration are 1 in 250.[4] The odds of critical penetration due to MMOD for STS-109 (HST SM-3B) were calculated to be 1 in 414.[5] Post-flight assessment of STS-109 yielded odds of 1 in 273. This agrees with the general trend of the MMOD models to slightly under-predict the odds of critical damage. While the odds of critical penetration for any one mission to either ISS of HST are of the same order of magnitude, the odds of critical penetration on ISS flights will be higher because the ISS does not have the flexibility that a HST mission has in accommodating MMOD protective attitudes. It is noteworthy to observe that the collective odds of thermal control system critical damage for the remaining 25 flights to complete the assembly of the ISS are not significantly increased with the addition of one HST Servicing Mission from the current value of 1 in 11.6.

C) LAUNCH and ASCENT CONSIDERATIONS

The CAIB determined that insulating foam that separated from the Shuttle's External Tank during the STS-107 ascent to orbit caused catastrophic damage to the Orbiter's reinforced carbon-carbon (RCC) on the leading edge of the left wing. The Board recommended:

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[4] Christiansen, Eric (NASA/JSC), Critical Meteoroid/Debris Impact Risk Breakdown by Mission Phase, September 17, 2003

[5] "Mission STS-109 OV-102 Flight 27 Meteoroid/Orbital Debris Post Flight Assessment, JSC-29815, September 2002

R3.2-1 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.

The NASA External Tank (ET) Project has developed a three-phase approach to complying with this recommendation. In Phase 1, they plan to develop, design, certify and implement the required modifications to the ET that will allow for a safe RTF. In Phase 2, they plan to implement additional enhancements to reduce debris risk. In Phase 3, they plan to develop, design, certify and implement modifications to the ET that will minimize debris sources in the critical debris zone.[6] The Shuttle Program estimates that these improvements will reduce the current odds of damage from a debris strike during ascent of 1 in 300 to approximately 1 in 600. The improvement in the odds of incurring debris damage will apply to all missions.

D) DISCUSSION

CAIB recommendation R6.4-1 requires that autonomous TPS inspection and repair capability eventually exist for all Shuttle flights while not requiring the initial autonomous capability to be in place by RTF. Currently, NASA plans to comply with this recommendation. In the event that non-repairable damage is detected, NASA plans to develop a Shuttle crew rescue flight capability. NASA's initial plans for this rescue capability included both Station and non-Station orbits. During launch, Shuttle abort risks are increased as the orbit inclination increases, and thus are more likely for flights to ISS than to HST.

The NASA Administrator has publicly stated "that a Hubble mission would require new and unique procedures that, taken individually, were surmountable but that in the aggregate were risks significantly higher than a shuttle mission to the space station." The aforementioned data and references from NASA RTF plans demonstrate that this statement cannot be supported. Given that NASA's plan is to be fully compliant with the CAIB recommendation to develop an autonomous inspection and repair capability, the aggregate risks are higher for ISS flights than for a flight to HST

When looked at from a TPS survivability perspective, there is a good basis for concluding that HST missions are as safe as or perhaps safer than ISS missions conducted in the same timeframe. HST missions will have:

1. A reduction in the risk of debris damage during ascent after the ET and SRB are modified; equivalent to ISS missions.
2. Impact sensors to identify impact locations and to focus early and time efficient inspections; in common with ISS missions.
3. Inspection sensors that will allow for accurate and time efficient inspections; in common with ISS missions.
4. A tile repair capability; in common with ISS missions.

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[6] Covey, Richard O., Return to Flight Task Group Interim Report, January 20, 2004

5. A rescue capability as readily implemented for an HST mission as for ISS, since the HST mission can be timed to be launched immediately before an ISS mission.
6. A better MMOD environment than an ISS mission and more flexibility than ISS flights to fly a protected on-orbit attitude.

The existence of or lack of a RCC repair capability will be a problem that is common to HST and ISS missions. While an HST mission will not have a safe haven capability, the risk associated with the absence of a safe haven is the same as ISS missions that fail to dock with the ISS.