Shuttle Radiator Protection Helps Prevent Mission Loss from Micrometeoroid and Orbital Debris

Eric Christiansen, *Johnson Space Center*
Dana Lear, *Johnson Space Center*
Eugene Stansbery, *Johnson Space Center*

NASA's Hypervelocity Impact Technology team, located at Johnson Space Center, routinely inspects the space shuttle vehicle after each mission for micrometeoroid and orbital debris (MMOD) damage. During the post-flight inspection after the Space Transportation System (STS)-128 flight of *Discovery*, NASA found 14 MMOD impacts on the crew cabin windows, 16 impacts on the wing leading edge and nose cap, and 21 impacts on the payload bay cooling radiators. Of these, one is perhaps the most important because it highlights a success story over 10 years in the making (figure 1).

Although the impact crater was not the largest damage found on the radiators, the crater was strategically placed directly over one of the cooling tubes bonded to the backside of the radiator face sheet. The impact crater is important because, if not for decisions to "harden" the shuttle fleet to the increasing orbital debris environment in the late 1990s, the impact would have breached the Freon cooling loop and, by flight rule, would have resulted in a leak rate high enough to result in an early mission termination (i.e., loss of mission).

The space shuttle was designed in the 1970s, before the risk from human-made orbital debris was widely recognized. The vehicle was originally designed with requirements for protection against only the micrometeoroid environment. Almost immediately, damage from orbital debris started showing up. The first significant impact was a 0.2-mm-sized paint chip that damaged a window during the STS-7 mission and required the window to be replaced prior to re-flight.

In the early 1990s, NASA applied the BUMPER code— a NASA MMOD risk analysis software—to predict the risk of damage to different surfaces of the spacecraft given their orbit, orientation, and the MMOD environment. Analysis showed that the shuttle risk was highly dependent on its flight attitude or orientation. The highest vulnerability to loss of mission was penetration of the cooling loop bonded to the inside surface of the radiator face sheet (figure 2a).

During this time, the on-orbit heat rejection system in the shuttle vehicle consisted of two Freon coolant loops routed through the radiator panels attached to the payload bay doors and accumulator tanks. There was no provision for isolating a leak in the system. Puncture of a tube by MMOD would totally deplete the coolant in one of the two loops, necessitating that approximately half of the heat sources (such as avionics in the crew cabin) be switched off. Flight rules under this situation required a next primary landing site abort; i.e., that the shuttle mission be aborted

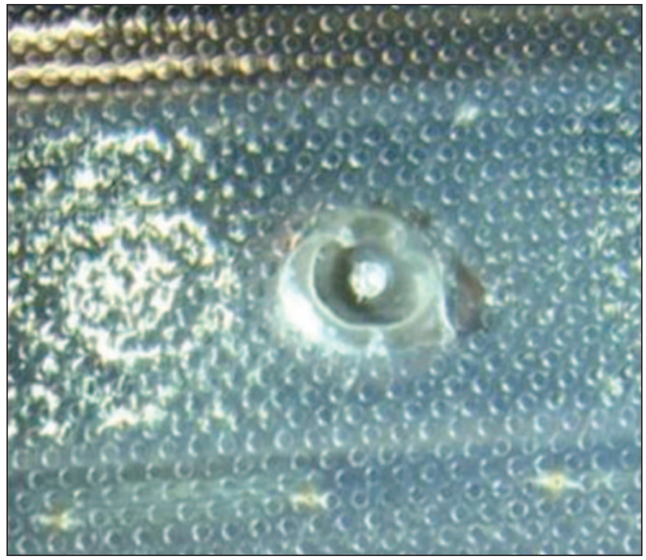

Fig. 1. *Impact crater on the radiator located on the interior of the shuttle payload bay doors. The impact was on an aluminum "doubler" directly over the tube carrying Freon coolant used to cool electronic equipment and avionics in the shuttle.*

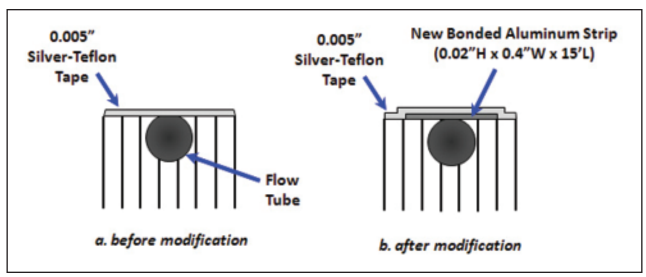

Fig. 2. *The shuttle radiators are curved panels, located on the inside of the payload bay door, that are exposed to space when the doors are open. The panels are a honeycomb structure sandwiched between a face sheet and a back sheet with a total thickness of either 12.7 or 22.9 mm. Aluminum tubes are bonded to the backside of the 0.28-mm-thick face sheet at intervals. This figure shows a cross-section of the honeycomb radiator revealing the configuration before and after the addition of the 0.5-mm aluminum "doubler."*

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immediately and preparations made to land at the next available primary landing site. Because coolant is lost quickly from the pumped flow system in the event of a leak, some of the avionics would be turned off during reentry and landing, decreasing the ability to recover from some other anomaly that could occur during this critical mission phase (due to loss of redundancy in the avionics systems).

The BUMPER predictions were put to the test during the first flight of the U.S. Microgravity Laboratory during STS-50. One of the experiments required that the shuttle fly nose up, payload bay into the velocity vector for 10 days of the 14-day mission. After much discussion with shuttle managers and impact tests on various spacecraft components that were contained in the payload bay of the orbiter, it was decided to fly the mission as planned. Fortunately, no MMOD impact breached the Freon cooling loop. However, post-flight inspection of the radiators showed that the number of impact features closely matched the preflight BUMPER predictions and were much higher than typical for shuttle missions flown with the payload bay facing Earth.

After STS-50, new flight rules were implemented that required the shuttle to fly with the payload bay to the Earth and the tail toward the velocity vector "unless payload or orbiter requirements dictate otherwise." This procedure worked well while the shuttle flew independently. Flights to the Russian space station Mir and later to the International Space Station, once again exposed the cooling loops to higher risk of MMOD impact for long periods while docked.

In 1997, modifications were approved by the Space Shuttle Program to "harden" the orbiters from the increasing orbital debris environment. Three of these modifications involved the Freon cooling system, two of which would prove critical for STS-128. First, an extra layer of 0.5-mm-thick aluminum (aluminum doubler) was bonded to the radiator face sheet directly over the cooling tubes (figure 2b). Automatic isolation valves were added to each coolant loop that could isolate a leak in a radiator panel from the rest of the Freon system (accumulator and pumps) so that sufficient Freon remained to activate the cooling system for all electronics during reentry, when heat is rejected to the flash evaporator system. If sufficient coolant was saved, the need for a next primary landing site abort was alleviated.

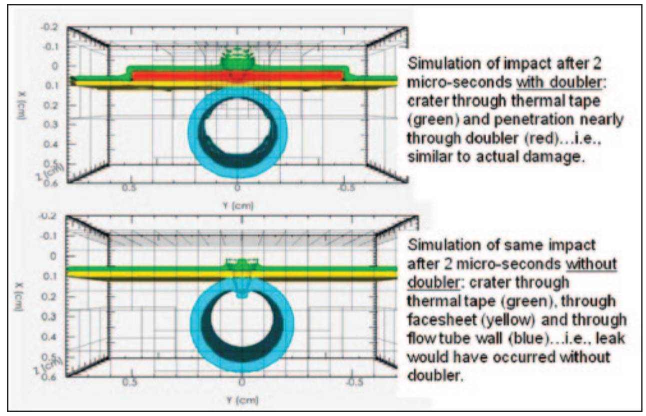

Fig. 3. *Hydrocode simulation of the impact with and without the aluminum "doubler." Without the doubler, the Freon cooling loop would have been breached.*

The modifications were incorporated into the shuttle fleet during routine maintenance between 1998 and 1999. These modifications, made 11 years prior to the STS-128 mission, saved the mission from early termination.

During the STS-128 mission, an orbital debris particle impacted the aluminum doubler directly above the Freon tube. Simulations show that had the doubler not been in place, the Freon tube would have been breached (figure 3). Without the second modification isolating the leak to the radiator panels, all of the Freon (which is under pressure) would have leaked from the system, requiring the shuttle to land within 24 hours and with reduced avionics.

This success story is a tribute to the entire NASA Hypervelocity Impact Technology, Orbital Debris and Space Shuttle management team. The Orbital Debris Program Office created the debris environment flux models that were based on solid science and measurement data. The Hypervelocity Impact Technology team applied the BUMPER code, which demonstrated the vulnerability of the Freon cooling system and its impact to overall mission risk, as well as evaluating risk mitigation techniques, such as the addition of aluminum doublers (which was eventually selected). Then, the Space Shuttle Program management made critical decisions in tight economic conditions to enhance the safety to the orbiters from the MMOD threat. A decade later, their hard work and tough decisions paid off.