Impact Testing of the Orbiter Thermal Protection System

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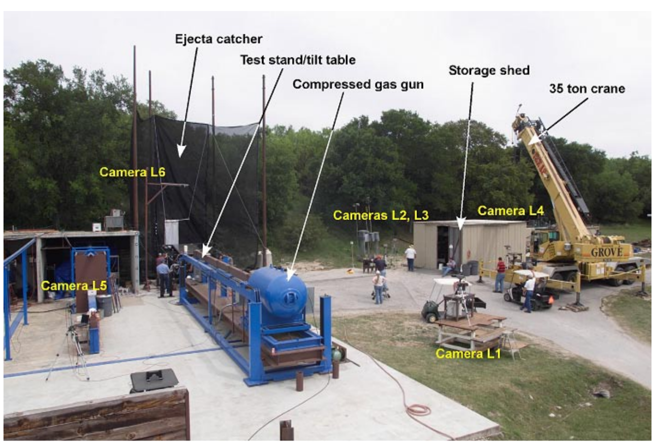
Ascent video and photography captured during the STS-107 mission showed debris from the external Tank (ET) striking the Orbiter Columbia's lower left wing 82 sec after launch (T+82). During the mission, photo analysis teams led by the Image Analysis Group in Astromaterials Research and Exploration Science (ARES) estimated an upper limit of approximately 50 cm for the size of the debris liberated with an uncertainty of ±25 cm. The visual evidence implicated the ET left bipod ramp as the source of the debris. Calculations of the debris velocity at impact ranged from 190 m/sec to 256 m/sec, depending on the various methods and assumptions used, with the most probable velocity estimated to be approximately 200m/sec.

The Columbia Accident Investigation Board (CAIB) considered the T+82 impact a likely initiating event of the accident requiring further evaluation. To replicate the impact, the Orbiter Vehicle Engineering Office chartered an Orbiter Thermal Protection Impact Test Team. The scope of the task undertaken by the team included design and construction of test article hardware, modification of facilities to conduct the tests, and detailed planning of test parameters. The impact test program



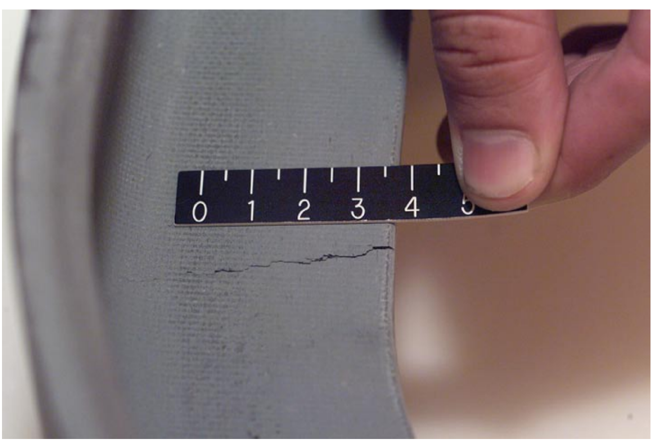
was conducted in close coordination with the CAIB and was led by the Hypervelocity Impact Group of ARES.

Because the impact occurred on the lower left wing of the Orbiter Columbia, test articles were developed for unique areas on the Shuttle surface; i.e., wing acreage tile and structure, the main landing gear door (MLGD), and the leading edge. The materials in these areas would have differing reactions to an impact by foam debris; likewise, a breach in these areas would yield varying Orbiter system responses during entry plume impingement. By the time testing began, the investigation teams determined the debris impacted the lower leading edge between panels 8L and 9L.

Engineers used the unique capabilities of the Southwest Research Institute (SwRI) to conduct the tests. The foam projectiles were launched to velocity using a large compressed-gas gun. The outdoor test site included a stand on which to mount targets and an 8-m-high curtain to catch ejected debris. As many as 13 high-speed video cameras were used to image both the projectile flight path and the impact event. Engineers used the data from these images to determine the projectile velocity and orientation at impact as well as the detailed motion and potential failure of the target after foam impact. The targets were equipped with strain gauges, accelerometers, and deflection gauges that enabled engineers to measure the strains in the Thermal Protection System (TPS) and the underlying Orbiter structure. As many as 275 channels of instrumentation data were collected during each test.

To prepare for the leading edge test program, five tests were conducted on LI-900 TPS tiles bonded to a left MLGD. These tests were used to evaluate the response of tile impacted by foam at representative velocities and angles and to verify test facility, instrumentation, and high-speed camera readiness. BX 250 foam at sizes (14,000, 20,000, 30,000 cm3), velocities (200 to 235 m/sec), and impact angles (5 to 13 deg) representative of the debris were shot at the MLGD with a large compressed-air gun facility at SwRI. The results demonstrated very little damage to the tiles for the range of parameters tested. None of the damage could be considered critical.

A leading edge test article of representative structural response was manufactured to enable impact testing of Reinforced Carbon-Carbon (RCC) panels, RCC T-seals, and TPS tile carrier panels. Tests on the RCC components were the priority. Due to the scarcity of available RCC flight panels, analysis techniques and impact tests on fiberglass panels of outer mold line geometry that were identical to that of the RCC panels were used to optimize the test conditions for each RCC test. Two RCC panel tests were ultimately conducted, one each on panels 6L and 8L. In total, five tests were conducted on fiberglass panels.



For the panel 6L test, a 20,000-cm3 BX 250 foam projectile impacted the panel at a velocity of 234 m/sec. A lower corner of the foam block first impacted the panel near the slip-side rib. The resulting crack, which measured approximately 14 cm, traversed the entire rib and lock and 1.9 cm onto the lower panel face. In addition, the panel 6L T-seal exhibited a crack 6.4 cm along its web.

The test conducted on panel 8L yielded results that were consistent with estimated damage inferred from onboard sensor data and forensic evidence. A foam block of the same mass and approximately the same size as that tested for panel 6L was launched to a velocity of 237 m/sec. The foam block initially impacted the panel several centimeters closer to the middle of the panel and was clocked at an angle such that most of the leading edge of the block loaded the panel. The foam block produced a hole 41 cm by 42.5 cm at the widest point. Investigators noted cracks along the lock and slip sides of the panel. The panel 8L T-seal was cracked at its lug, which opened a slight gap between the panel and the seal. Investigators found the RCC materials displaced from the panel inside the test article. The largest two fragments were approximately 20 cm by 33 cm and 19 cm by 29 cm. Joint scenario testing of TPS materials ended upon completion of this test.