Detection of Debris

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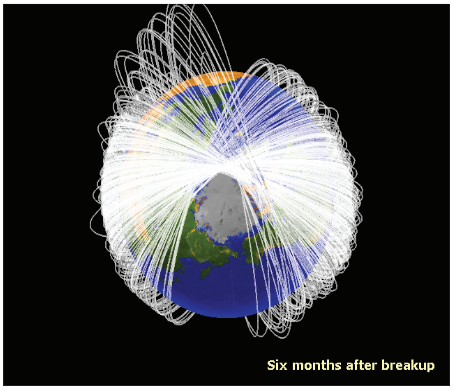

Figure 2. The debris cloud from the Fengyun-1C spacecraft is rapidly dispersing.

concentration near the breakup altitude of approximately 850 km. The debris orbits are rapidly spreading (Figure 2) and will essentially encircle the globe by the end of the year. Only a few known debris had reentered more than five months after the test, and the majority will remain in orbit for many decades.

The large number of debris from Fengyun-1C are posing greater collision risks for spacecraft operating in low Earth orbit. The number of close approaches has risen significantly. On 22 June, NASA's Terra spacecraft had to execute a collision avoidance maneuver to evade a fragment from Fengyun-1C that was on a trajectory which would have passed within 19 meters of Terra.

After a flurry of satellite breakups in the first quarter of 2007, the next three months witnessed only one minor fragmentation classified as an anomalous event. An anomalous event is normally characterized by the release of only one or a few debris with very small separation velocities. The debris appear to "fall-off" their parent satellites, probably due to environmental degradation or small particle impacts (Johnson, 2004).

In April a new piece (U.S. Satellite Number 31408) from the derelict U.S. Seasat spacecraft (International Designator 1978-064A, U.S. Satellite Number 10967) was detected. This was the 15th debris from Seasat cataloged since 1983 and the fourth seen during the past four years (Figure 3). These debris exhibit a variety of ballistic coefficients, but all decay relatively rapidly compared to Seasat itself, which is in a stable, nearly circular orbit near 750 km. Additional debris have been briefly detected from Seasat, but they have reentered prior to being cataloged. The source of the debris could be either the spacecraft or the Agena upper stage to which it is still attached.

Early in 2006 an anomalous event involving the 46-year-old Vanguard 3 was detected (Orbital Debris Quarterly News, 10-3, p. 2). A second piece has now been cataloged (U.S. Satellite Number 31405), and it is likely to have also separated from Vanguard 3 in 2006, possibly about the time of the first piece. The newly discovered debris is decaying at a slower pace than the debris seen last year, but both are falling back to Earth much faster than Vanguard 3 from its orbit of 500 km by 3300 km.

1. Johnson, N.L., "Environmentally-Induced Debris Sources", *Advances in Space Research*, Vol. 34 (2004), Issue 5, pp. 993-999. ♦

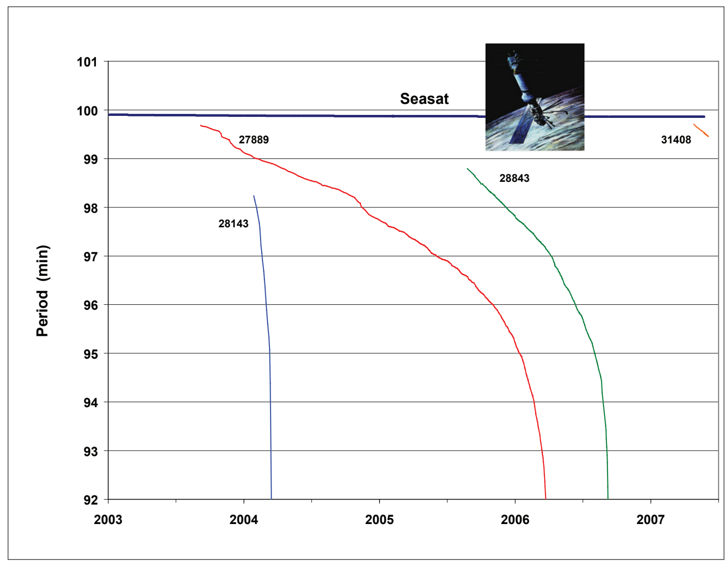

Figure 3. A new piece of debris separated from the Seasat spacecraft in early 2007.

PROJECT REVIEWS

Investigation of MMOD Impact on sts-115 Shuttle Payload Bay Door Radiator

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1. Introduction

The Orbiter radiator system consists of eight individual 4.6 m x 3.2 m panels located with four on each payload bay door. Forward panels #1 and #2 are 2.3 cm thick while the aft panels #3 and #4 have a smaller overall thickness of 1.3 cm. The honeycomb radiator panels consist of 0.028 cm thick Aluminum 2024-T81 facesheets and Al5056-H39 cores. The facesheets are topped with 0.005 in. (0.127 mm) silver-Teflon tape. The radiators are located on the inside of the shuttle payload

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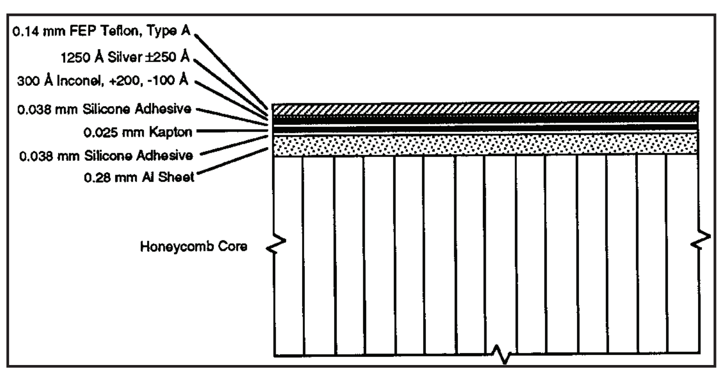

Figure 1 Cross section of orbiter radiator facesheet.

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bay doors, which are closed during ascent and reentry, limiting damage to the on-orbit portion of the mission.

2. Post Flight Inspection

Post-flight inspections at the Kennedy Space Center (KSC) following the STS-115 mission revealed a large micrometeoroid/orbital debris (MMOD) impact near the hinge line on the #4 starboard payload bay door radiator panel. The features of this impact make it the largest ever recorded on an orbiter payload bay door radiator. The general location of the damage site and the adjacent radiator panels can be seen in Figure 2. Initial measurements of the defect indicated that the hole in the facesheet was 0.108 in. (2.74 mm) in diameter. Figure 3 shows an image of the front side damage. Subsequent observations revealed exit damage on the rear facesheet. Impact damage features on the rear facesheet included a 0.03 in. diameter hole (0.76 mm), a ~0.05 in. tall bulge (~1.3 mm), and a larger ~0.2 in. tall bulge (~5.1 mm) that exhibited a crack over 0.27 in. (6.8 mm) long. A large ~1 in. (25 mm) diameter region of the honeycomb core was also damaged. Refer to Figure 4 for an image of the backside damage

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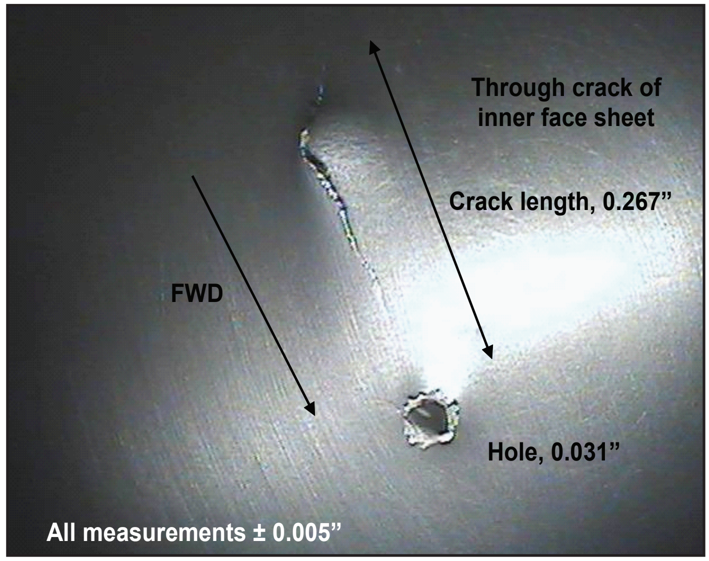

Figure 4. Rear facesheet damage on starboard radiator #4.

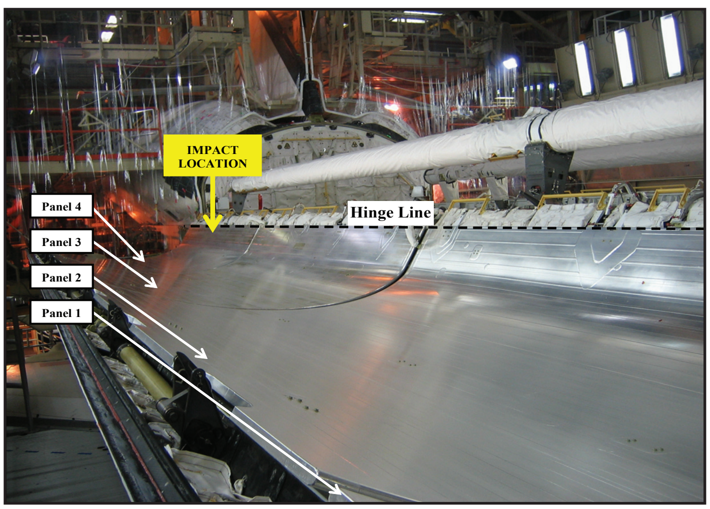

Figure 2. Orbiter payload bay door radiators (starboard panels 1-4 shown).

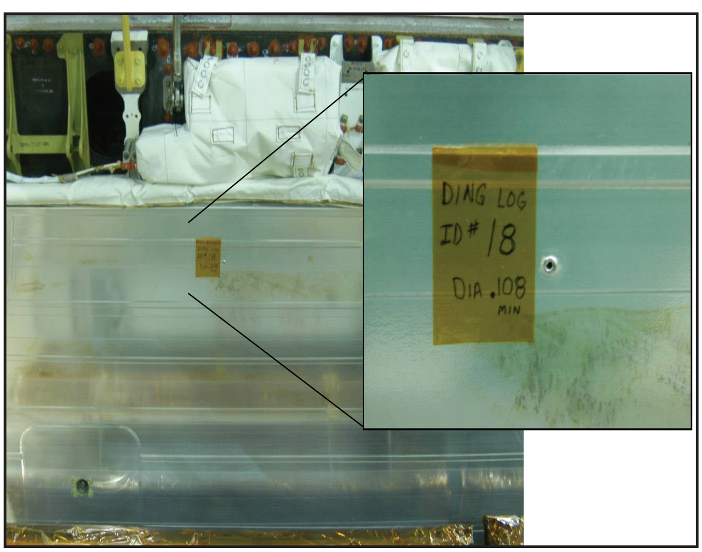

Figure 3. Front facesheet damage on starboard radiator #4.

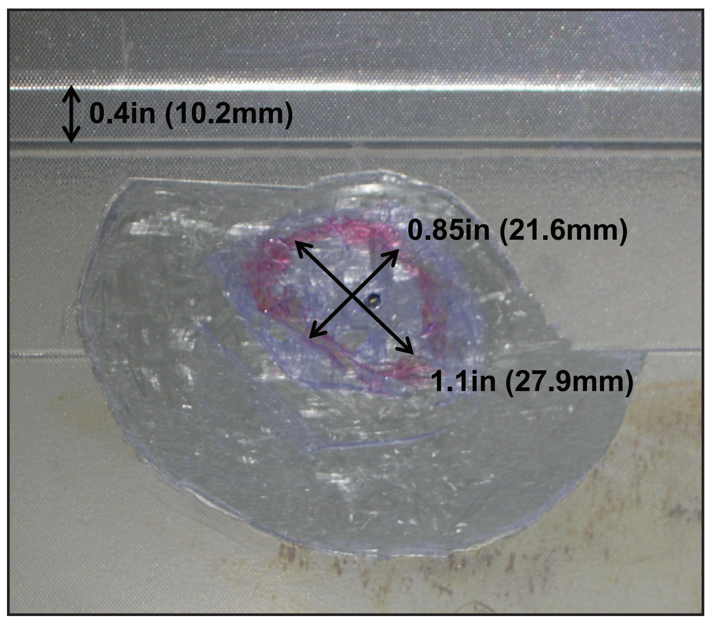

Figure 5. Front facesheet with thermal tape removed. Extent of damaged facesheet is hghlighted.

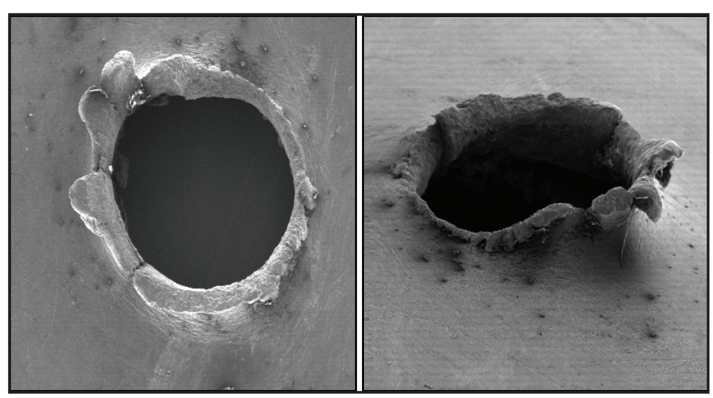

Figure 6. SEM images of hole in front facesheet. Asymmetric nature of lip can be seen in the oblique view.

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to the panel. No damage was found on thermal blankets or payload bay door structure under the radiator panel.

Figure 5 shows the front facesheet with the thermal tape removed. Ultrasound examination indicated a maximum facesheet debond extent of approximately 1 in. (25 mm) from the entry hole. X-ray examinations revealed damage to an estimated 31 honeycomb cells with an extent of 0.85 in. x 1.1 in. (21.6 x 27.9 mm).

3. SEM/EDS Analysis

Pieces of the radiator at and surrounding the impact site were recovered during the repair procedures at KSC. They included the thermal tape, front facesheet, honeycomb core, and rear facesheet. These articles were examined at JSC using a scanning electron microscope (SEM) with an energy dispersive x-ray spectrometer (EDS). Figure 6 shows SEM images of the entry hole in the facesheet. The asymmetric height of the lip may be attributed to projectile shape and impact angle. Numerous instances of a glass-fiber organic matrix composite were observed in the facesheet tape sample. The fibers were approximately 10 micrometers in diameter and variable lengths. EDS analysis indicated a composition of Mg, Ca, Al, Si, and O. Figures 7 and 8 present images of the fiber bundles, which were believed to be circuit board material based on similarity in fiber diameter, orientation, consistency, and composition.

4. Hypervelocity Impact Tests

A test program was initiated in an attempt to simulate the observed damage to the radiator facesheet and honeycomb. Twelve test shots were performed using projectiles cut from a

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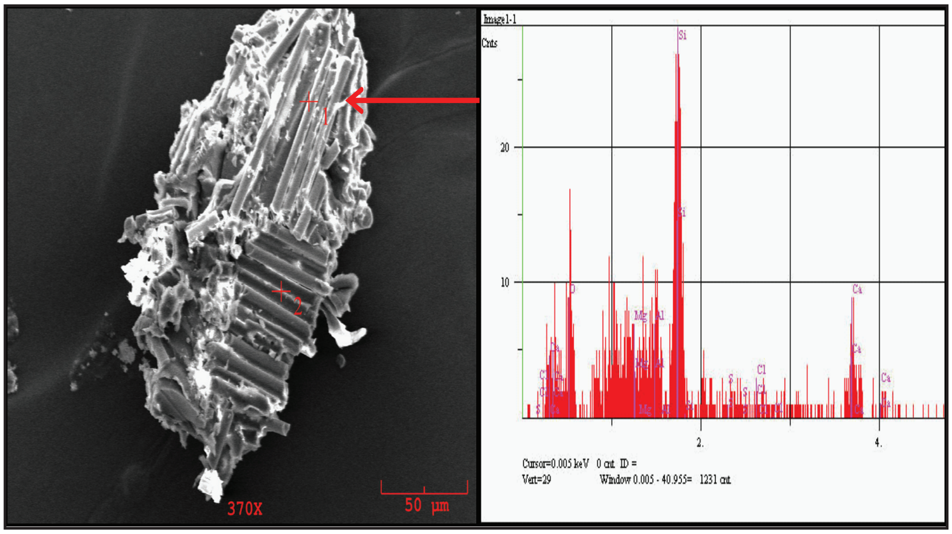

Figure 7. Example SEM image and EDS spectra of circuit board fragment.

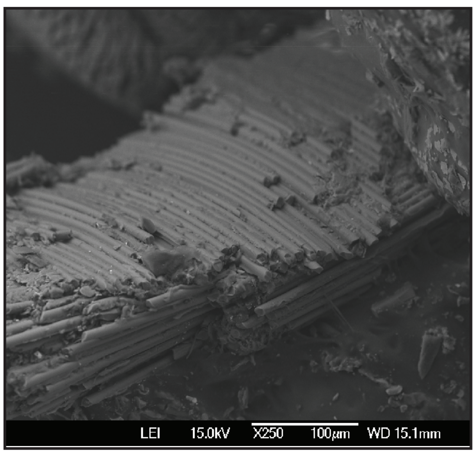

Figure 8. SEM image of circuit board fragment.

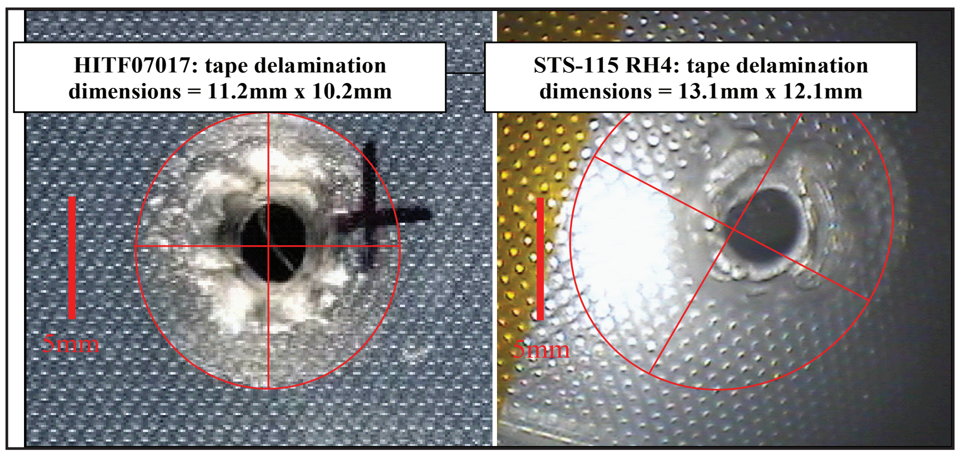

Figure 9. Entry hole in upper facesheet.

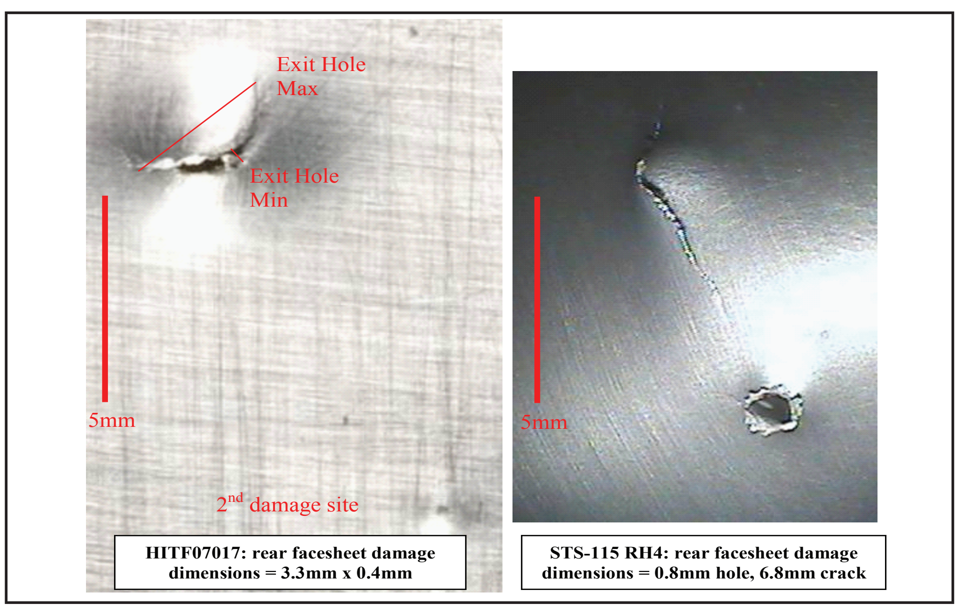

Figure 10. Exit hole in lower facesheet.

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1.6 mm thick fiberglass circuit board substrate panel. Results from test HITF07017, shown in figures 9 and 10, correlates with the observed impact features reasonably well. The test was performed at 4.14 km/sec with an impact angle of 45 degrees using a cylindrical projectile with a diameter and length of 1.25 mm. The fiberglass circuit board material had a density of 1.65 g/cm^3, giving a projectile mass of 2.53 mg.

5. Impact Risk

An analysis was performed using the Bumper code to estimate the probability of impact to the shuttle from a 1.25 mm diameter particle. Table 1 shows a 1.6% chance (impact odds = 1 in 62) of a 1.25 mm or larger MMOD impact on the radiators of the vehicle during a typical ISS mission. There is a 0.4% chance (impact odds = 1 in 260) that a 1.25 mm or larger MMOD particle would impact the RCC wing leading edge and nose cap during a typical mission. Figure 11 illustrates the vulnerable areas of the wing leading edge reinforced carbon-carbon (RCC), an area of the vehicle that is very sensitive to impact damage. The highlighted red, orange, yellow, and light green areas would be expected to experience critical damage if impacted by an OD particle such as the one that hit the RH4 radiator panel on STS-115. ♦

Table 1. MMOD impact risk for a typical shuttle mission to ISS from particles 1.25 mm and larger.

Region	MMOD Impact Risk	Odds of Impact
Upper TPS	7%	1 in 15
Lower TPS	1.7%	1 in 59
Radiators	1.6%	1 in 62
Wing Leading Edge and Nose Cap RCC	0.4%	1 in 260
Windows	0.04%	1 in 2500
Total Vehicle	10%	1 in 10

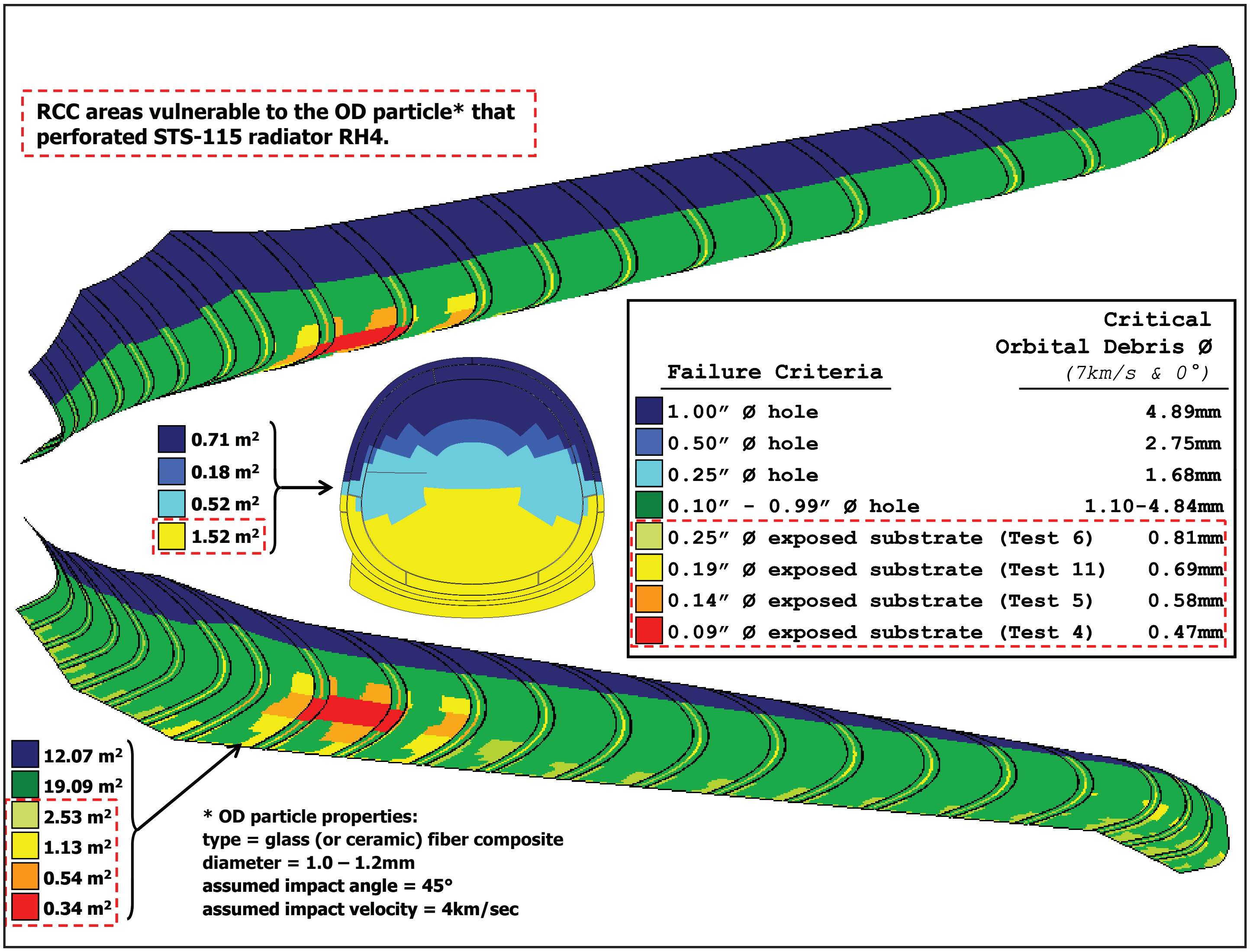

Figure 11. MMOD Failure Criteria for RCC: wing leading edge, nose cap and chin panel..