The Performance of the Orbiter Wing Leading Edge Impact Detection System During Space Shuttle Ascent

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As part of the shuttle return-to-flight effort following the *Columbia* accident, NASA developed an on-board instrumentation system to improve awareness of ascent debris impacts to the orbiter wing leading edge (WLE). The Wing Leading Edge Impact Detection System (WLEIDS) consists of an array of 66 accelerometers per wing together with associated electronic components that acquire and transmit measured data to the ground during flight. Accelerometers are located behind the orbiter wing spar at the four attach locations of each WLE panel (figure 1).

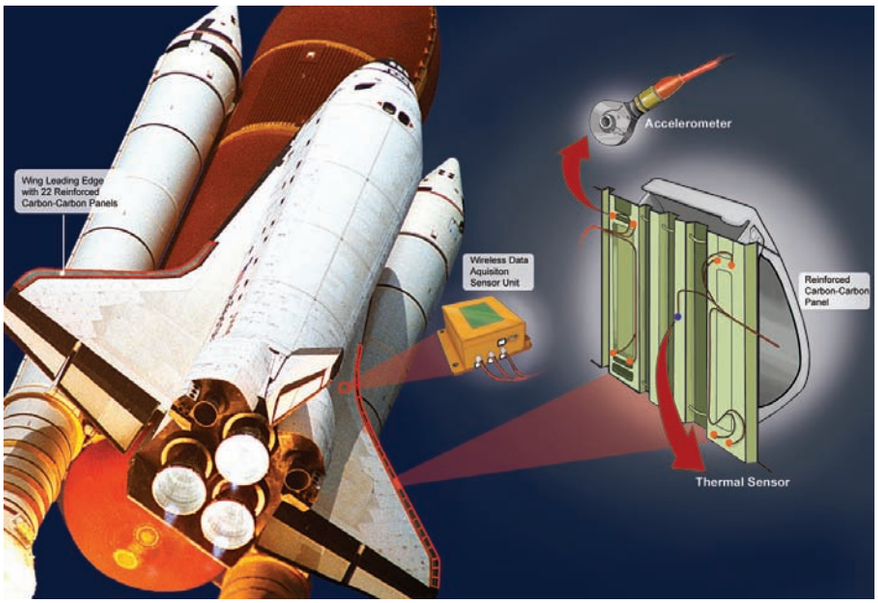

Fig. 1. *WLEIDS accelerometers and wireless data acquisition sensor units.*

During shuttle ascent, WLEIDS accelerometer data are collected by wireless data acquisition sensor units mounted in wing cavities near the fuselage, downloaded through wireless relay units to the astronauts' on-board laptops, and accessed by ground teams for engineering analysis in the Mission Control Center at Johnson Space Center.

Shuttle ascent is a highly dynamic period that includes main engine ignition, solid rocket booster (SRB) ignition, roll maneuvers, maximum dynamic pressure, SRB separation, and other significant loading events, all of which are captured in WLEIDS accelerometer data. The challenge for the WLEIDS engineering team is to discern from these dynamic data whether an impact has occurred to the WLE and, if so, when and where it occurred (for potential corroboration with ground imagery) and how much energy was associated with it (for damage severity assessments).

The Southwest Research Institute in San Antonio, Texas, developed WLEIDS data analysis methods and impact response prediction models anchored by more than 100 ascent debris impact tests. Test projectiles included various sizes and velocities of shuttle external tank (ET) foam and ablator, ice, and metal impacting three different, full-scale WLE test articles representing the various designs and regions of the shuttle wing structure. The "T-35" test article, representing the wing section around WLE panels 16R and 17R, is shown in figure 2.

Once the impact response prediction model was correlated by testing, we performed a statistical analysis on the results to define the damage probabilities associated with the WLEIDS impact indications measured at specific orbiter WLE panel locations. During flight, by mission elapsed time (MET) 18 hours, a full report of WLEIDS ascent impact indications is provided to the WLE hardware engineers, including structural dynamic characteristics and damage probabilities of each ascent impact. The hardware team considers WLEIDS results in a review of on-orbit WLE inspection imagery and, prior to orbiter re-entry, ultimately includes these results in an integrated assessment of WLE structural integrity.

In a typical shuttle flight, WLEIDS detects about 100 low-energy, non-damaging ascent debris impact indications. These indications are believed to be associated with small foam ("popcorn" foam) releases that occur due to aeroheating of the ET, causing internal pressure to build up and small divots in the tank foam insulation to separate. In figure 3, a typical ET aeroheating curve is

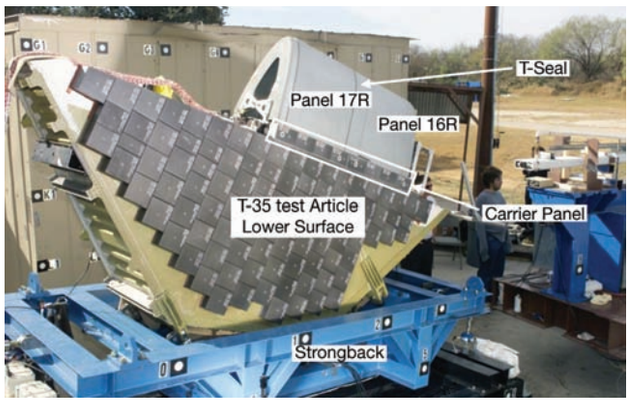

Fig. 2. *T-35 orbiter WLE test article.*

overlaid on a cumulative tally of WLEIDS ascent debris impact indications and their associated root-mean-square peak accelerations [gravity, root mean square (Grms)] for 10 flights, flights STS-114 through STS-124. Note that while the aeroheating curve exhibits a clear "double-hump" characteristic, the second WLEIDS data "hump" is much less pronounced. This is thought to be because, after an MET of approximately 165 seconds, little atmosphere remains to create notable drag forces on the foam and cause a significant velocity differential between a released piece of foam and the ascending orbiter. So, although the number of popcorn foam releases increases during this second hump, the foam does not have enough impact energy to register on the WLEIDS.

In summary, analysis methods for, and ascent damage predictions from, WLEIDS are grounded in an extensive test and model development program. WLEIDS data were also successfully used to confirm a known, in-flight phenomenon: "popcorn" foam release. As a result, we are highly confident that WLEIDS can detect both a large foam impact as well as smaller, damaging and non-damaging ascent debris impacts to the WLE such as the one that critically damaged the Space Shuttle *Columbia* orbiter.

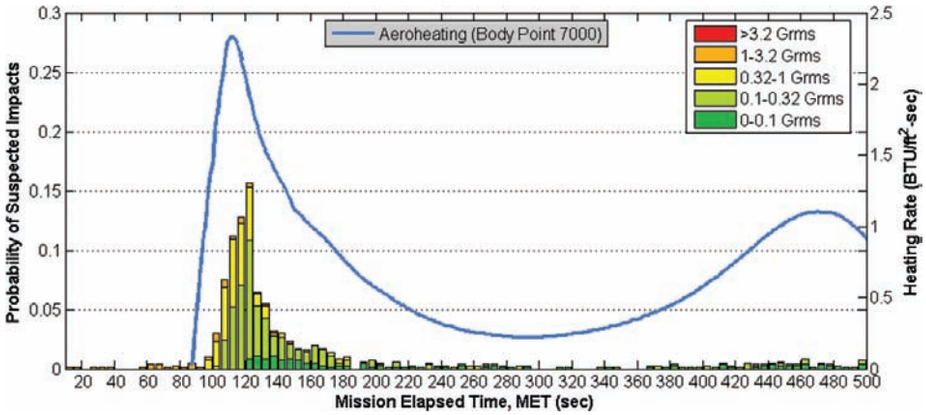

Fig. 3. *WLEIDS ascent debris impact indications (STS-114 to STS-124) overlaid with ET aeroheating.*

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