Space Shuttle Debris Transport

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Debris Sources

Liftoff Debris
- rust, uncontained hardware, etc.

Ascent Debris
- foam, ice, gap fillers, ceramic inserts, many other smaller and lower likelihood sources.

Orbital Debris
- > 3 km/sec
- > 9,800 ft/sec
Probabilistic Debris Process

\[
Pr(\text{failure}) = Pr(E_1 \cap E_2 \cap E_3)
= Pr(E_1)Pr(E_2 \mid E_1)Pr(E_3 \mid E_1 \cap E_2)
\]

- **E₁** Debris Released
  - Void distributions, material properties, heating, etc.

- **E₂** Debris Impacts Surface
  - Flowfield, mass, drag coefficient, crossrange, etc.

- **E₃** Impact Exceeds Capability
  - RCC, tile, windows, ...
  - \( f(\text{mass, velocity, angle, material, ...}) \)

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**Figure 3.** Scanning electron microscopy photomicrograph (30X), from Ref. 6, p. 94.

**ET TPS Failure Modes**

The operating environment of the ET is a complex combination of thermal conditions, aerodynamics heating, aerodynamic and acoustic loads, and mechanical loads. Internally, the ET shell structure contains various amounts of cryogenic liquid fuels, while externally the ET is exposed to ambient air temperature and pressure prior to launch and aerodynamic heating and pressure, vibro-acoustic loading, and external pressure gradients during ascent. For weight savings, the structural capacity of the ET shell material is highly exploited. The structurally tailored shell walls of the LH₂ and LO₂ tanks are quite thin – in some regions the ratio of shell radius to shell thickness is much less than 0.001. As a result, the ET shell wall (substrate) deformations can be significant and may be a secondary contribution to many of the ET TPS failure modes.

The primary ET TPS failure modes appear to be a result of consequences stemming from the SOFI application process and/or the overall ET system-level design. Known failure modes for the ET SOFI system include:

- **Substrate debond** – This failure mode (see figure 4) can result from poor adhesion of the SOFI to the ET aluminum substrate surface. Moreover, peel stresses caused by the thermal gradient and mismatch in thermal expansion between the substrate and the TPS, large-magnitude ET shell wall deflections (i.e., hoop stretching of the cellular structure), and rapidly varying severe ET shell wall deflection gradients (“accordion mode”) in the axial and/or hoop directions are major contributors to this failure mode. A key concern of an accordion mode is the high curvature of the local, short-wavelength deformation modes. These deformation modes can result in local compression of the foam and potentially create pockets.
Enginee ing Tools

Modeling & Simulation

Ground/Subscale Test

Flight/Full scale Test

Space Shuttle Debris Transport Assessments
Eliminating Debris Sources

STS-1 thru 4 many modifications
Return To Flight & subs modifications
Multiple ice/frost ramp redesigns
LH$_2$ flange process changes
Airloads reviews
Aerothermal support

RCS Tyvek® covers
Bipod Ramp Removal
±Z Aero-Vent Modification

Modified Aft Longeron
LO$_2$ feedline bracket redesigns
STS-121 PAL Ramp Removal
Prelaunch Iceball Assessment Tools
Inflight Damage Assessments

STS-118
Tile Damage

Insight into local flow properties

Post flight Image

$M_\infty = 18$
$\alpha = 35^\circ$

AIAA 2008-4246
Inflight/Postflight Debris Assessments

Mach 3 Simulation of tile ceramic insert debris

Reaction Control System cover trajectory reconstruction