Micrometeoroid and Orbital Debris (MMOD) Risk Overview

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Agenda

- Background on micrometeoroid and orbital debris (MMOD) environment
- MMOD shielding overview
- ISS MMOD risk issues
  - Radiators
  - Solar arrays
  - Solar array masts
  - EVA Handrails
  - Hardware behind bumpers or covers
  - Return vehicle thermal protection systems (TPS)
MMOD Environment Models

- **Orbital Debris provided by JSC & is the predominate threat in low Earth orbit**
  - ORDEM 3.0 is latest model (released December 2013)
  - Man-made objects in orbit about Earth impacting up to 16 km/s
    - average 9-10 km/s for ISS orbit
  - High-density debris (steel) is major issue
  - [http://orbitaldebris.jsc.nasa.gov/](http://orbitaldebris.jsc.nasa.gov/)

- **Meteoroid model provided by MSFC**
  - MEM-R2 is latest release
  - [http://www.nasa.gov/offices/meo/home/index.html](http://www.nasa.gov/offices/meo/home/index.html)
  - Natural particles in orbit about sun
    - Mg-silicates, Ni-Fe, others
  - Meteoroid environment (MEM): 11-72 km/s
    - Average 22-23 km/s
MMOD Environment Models

- Meteoroids consist of background sporadic flux (static), and streams from meteor showers (variable)
  - Occasionally, showers can turn into storms
- Orbital Debris is dynamic, changing as function of the rate of on-orbit explosions & collisions, launch rate and atmospheric drag/solar activity

Note, Spatial Density is proportional to impact risk
Cataloged objects >10 cm diameter
1970

Cataloged objects >10 cm diameter
Cataloged objects >10 cm diameter

1980
1990

Cataloged objects >10 cm diameter
National Aeronautics and Space Administration

Cataloged objects >10 cm diameter

2000

Cataloged objects >10 cm diameter
National Aeronautics and Space Administration

2010

Cataloged objects >10 cm diameter
National Aeronautics and Space Administration

Effects of Micrometeoroid and Orbital Debris (MMOD) Impacts

- Even small MMOD impacts can cause a lot of damage
  - Hypervelocity MMOD impacts represent a substantial threat to spacecraft
  - Rule of thumb: at 7km/s, aluminum sphere can penetrate completely through an aluminum plate 4x the sphere’s diameter

Damage from a 1.3cm diameter sphere at 7km/s

Comparison of size of projectile to size of impact crater
**Monolithic versus Stuffed Whipple Shield Weight Comparison of Equal-Performance Shielding**

**Aluminum “Monolith” Shield**
29.1 pounds per square foot

- Aluminum sphere (debris simulant)
- 0.5” diameter
- Impact Velocity (7 km/s)
- 2.00” (solid)
- (spacecraft exterior)
- (spacecraft interior)

**Stuffed Whipple Shield**
4.5 pounds per square foot

- Aluminum sphere (debris simulant)
- 0.5” diameter
- Impact Velocity (7 km/s)
- 0.08” aluminum
- Thermal insulation
- 6 layers Nextel® AF-62
- 6 layers Kevlar® Style 710 (or KM2-705)
- 0.188” aluminum

**These shields can stop a 0.5” diameter aluminum debris projectile impacting at 7km/s, but the Stuffed Whipple shield weighs 84% less (94% if rear wall is excluded) and costs much less to launch to orbit**
ISS shielding overview

- Several hundred MMOD shields protect ISS, differing by materials, standoff distance, and capability
- Heavier shields on front & sides (where we expect most MMOD impacts), less capable shielding on aft, nadir and visiting vehicles

colors represent different MMOD shield configurations
Issues: MMOD Damage to ISS Radiators

- MMOD impact damages observed to ISS radiator panels during Russian EVA (June 2013)
MMOD Damage to ISS Radiators
MMOD Damage to ISS Radiators (US)

- MMOD impact damages observed to ISS radiator panels (Aug. 2013)
P4 photovoltaic radiator

- Initial indication found on 6/30/2014
Measurement of P4-PVR Radiator Damage
“2A” Side of Panel 3
MMOD damage caused disconnected bypass diode, leading to cell overheat damage.
ISS Solar Array Mast

- Deployable structural booms or masts used to support ISS solar arrays
MMOD Damage to ISS Solar Array Masts

- Elements of the solar array masts have been damaged from MMOD impacts
Hypervelocity impact tests

- Mast elements have been hypervelocity impact tested and structurally tested to assess residual strength for ISS life extension
Many craters noted to ISS handrails and EVA tools
Sharp crater lips have lead to cuts on EVA gloves
EVA terminated early on STS-118 due to glove cuts
Modifications to EVA suit and ISS EVA procedures necessary to reduce cut glove risk from MMOD damage
Ku-band antenna

- An MMOD Strike was seen on the ISS Ku Antenna Gimbal Gear Cover. The image was captured during Mission ULF2 / STS-126.
- Interior damage?
Thermal protection systems (TPS) for crew return vehicles

- MMOD risk to thermal protection system (TPS) of ISS crew return vehicles (Soyuz, Commercial vehicles) is high
  - Concern is TPS damage that can lead to loss-of-vehicle during reentry
  - Issue can be mitigated by inspection and repair or safe-haven (not Program baseline)
BACKUP CHARTS
During STS-120 two solar array wings were removed from Z1 truss and relocated to P6 location. During re-deployment, the 4B solar array wing was torn in two places, due to a snagged guide wire. The guide wire was removed and “cuff-links” added to stabilize the array.
7 of 21 wires in the guide wire cable were broken, causing the guide wire to hang-up in a solar array grommet. 3 of the 7 cut wires exhibited evidence of extensive melt at broken ends, indicative of MMOD impact.
MMOD Damage to ISS

- MMOD impact damages observed to radiator panel during EVA-20 (Nov. 2012)
Observed Spacecraft MMOD Impacts
Shuttle Windows

Sampling of Shuttle Window MMOD Impact Craters
(all displayed on same dimensional scale)
MMOD Risk Assessment Process

- Process used to identify MMOD risk drivers, evaluate risk mitigation options & optimization, verify compliance with protection requirements.
ISS Service Module Shielding

- Service Module (SM) identified as high penetration risk using Bumper risk analysis
  - large cone region
  - forward sides of small diameter cylinder
- Shields designed and tested, EVA installed
  - 23 augmentation shields for the cone region
  - 5 augmentation shields for the cylinder region
- 28 shields reduced SM MMOD risk by 30%

EVA Installation
- 23 “conformal” panels on cone region
- 5 panels on small diameter cylinder