NASA WG3 MMOD Protection Summary

34th Interagency Space Debris Coordination Committee (IADC)
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Summary of MMOD Protection Activities

- **Prepared inputs to AI 31.3 Vulnerability Report**
  - IT32-13: Batteries (summary charts 3-5)
  - IT32-21: MLI
  - IT32-18: Fluid Lines (in work)
  - IT32-11: Cables (in work)

- **International Space Station (ISS)**:
  - Identified MMOD damage in on-orbit photos of ISS hardware (chart 6)
  - Performing on-orbit inspection of visiting vehicle thermal protection systems prior to undock
  - Continue damage detection & repair work (joint international working group)

- **Multipurpose Crew Vehicle (Orion), Commercial Crew & Resupply Vehicles**:
  - Performed risk assessments and hypervelocity impact tests to verify compliance to MMOD requirements
  - Performed post-flight MMOD damage inspections of SpaceX Dragon cargo vehicle after ISS resupply missions (SpX-5 and SpX-6 missions)

Lithium-Ion Battery Tests

- Several hypervelocity impact tests performed on Li-ion battery cells
- Cells were fully-charged prior to impact and protected by honeycomb panel and additional shielding materials
- Two cells in each test ("primary" was impacted, "secondary" cell was in close proximity to determine if thermal effects propagate

Test #	Projectile Diameter (mm)	Impact Obliquity (°)	Impact Speed (km/s)	Cell Damage Measurements (mm)
HITF12143	10.0	0	6.86	Primary cell-Perforated with peak temperature of 184°C Secondary cell-No ignition or thermal runaway
HITF12144	10.0	0	7.02	Primary cell-Perforated, no ignition, peak temperature 194°C Secondary cell- Thermal runaway peaking at 531°C
HITF12145	10.0	30	7.05	Primary cell-No Perforation Secondary cell-No Perforation
HITF12147	13.5	45	6.88	Primary cell-Perforated with peak temperature of 193°C Secondary cell- Thermal runaway peaking at 315°C
HITF12148	10.0	0	7.19	Primary cell-Perforated, no ignition Secondary cell-No ignition or thermal runaway

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Lithium-Ion Battery Tests
HITF-12143, 1cm diameter Al @ 6.86 km/s

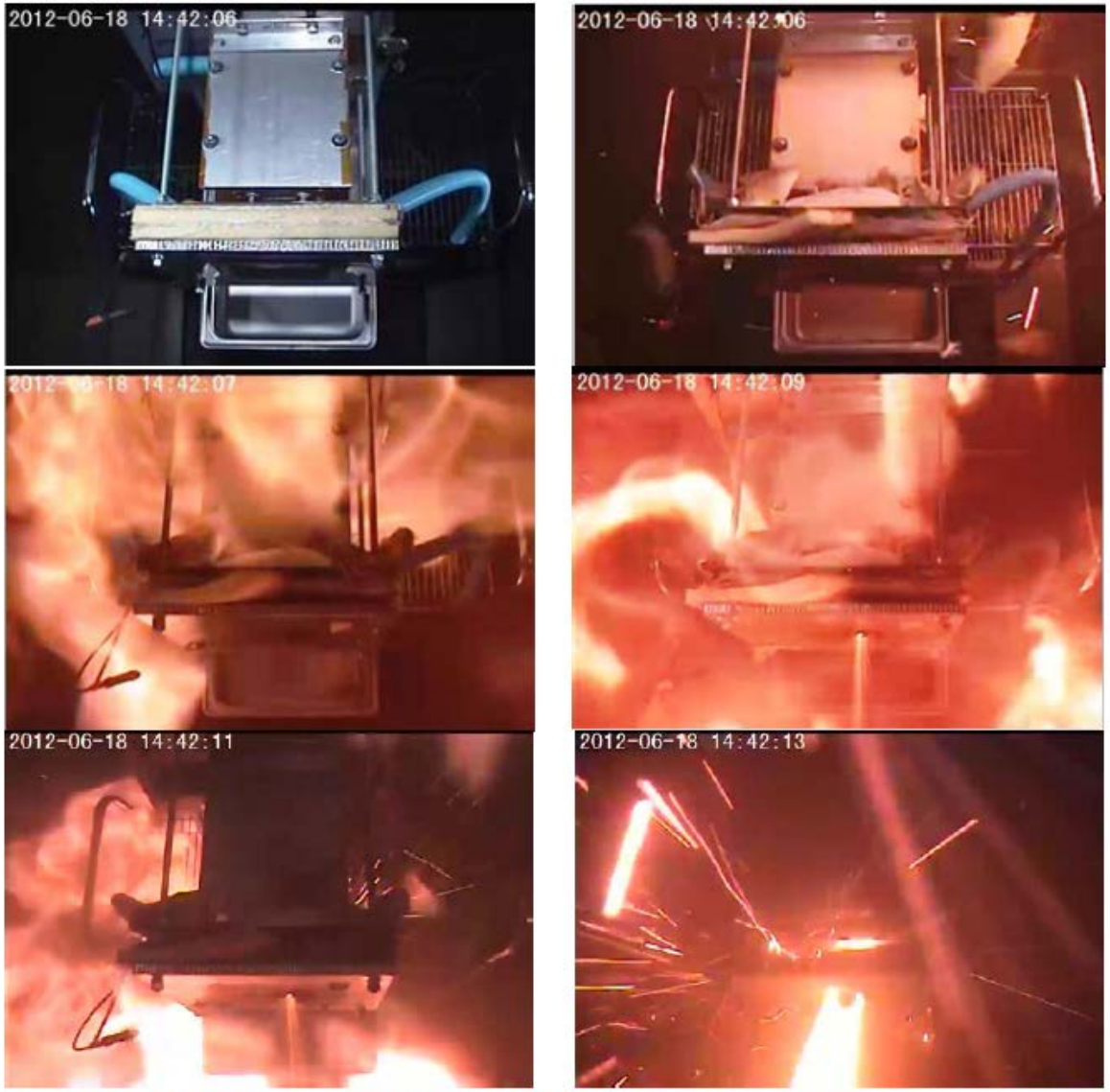

Figure 1.2-1. HITF12143 visible video frames at 1s-2s intervals after impact.

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Lithium-Ion Battery Tests
HITF-12143, 1cm diameter Al @ 6.86 km/s

- Energetic response to hypervelocity impact

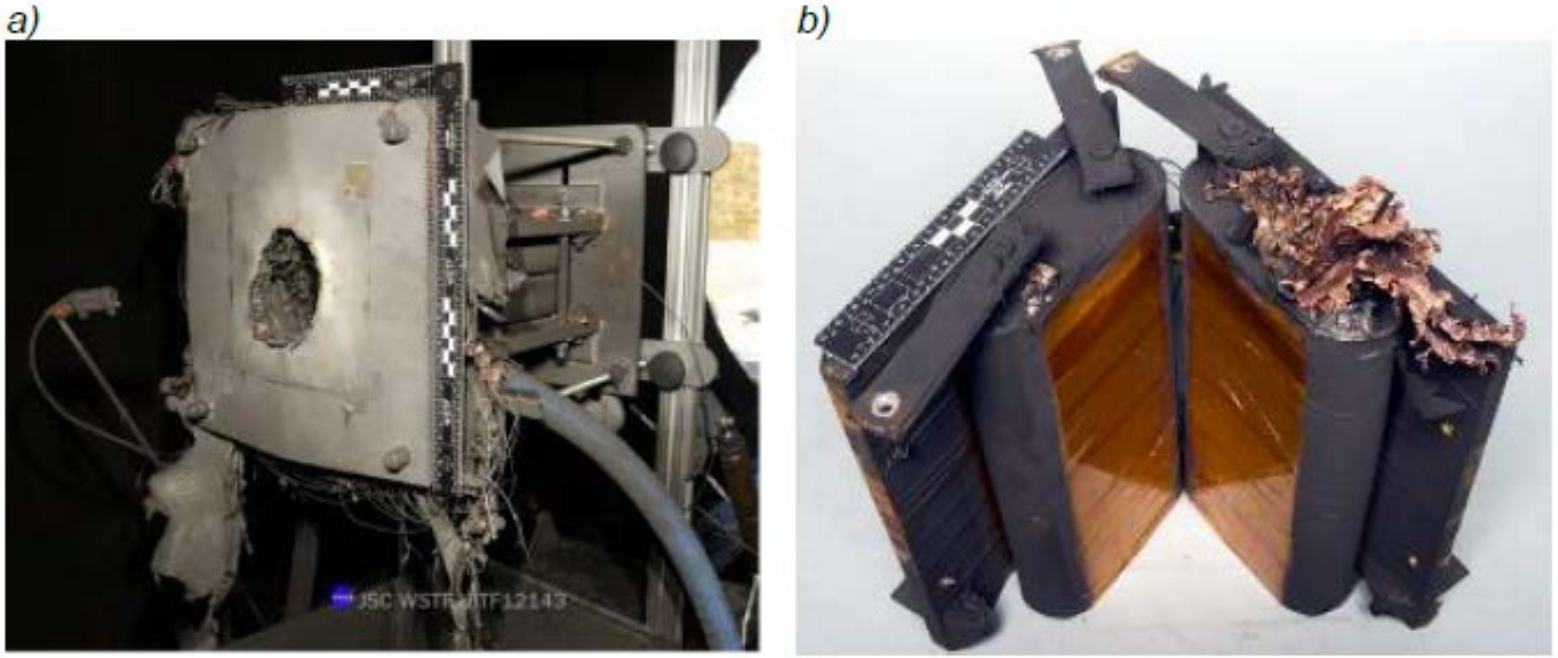

Figure 1.2-2. After test imagery of HITF12143 a) shield with 9.5cm diameter through-hole, and b) cell close-up with impacted cell on right showing molten material from cell interior that was ejected and deposited on exterior of cell.

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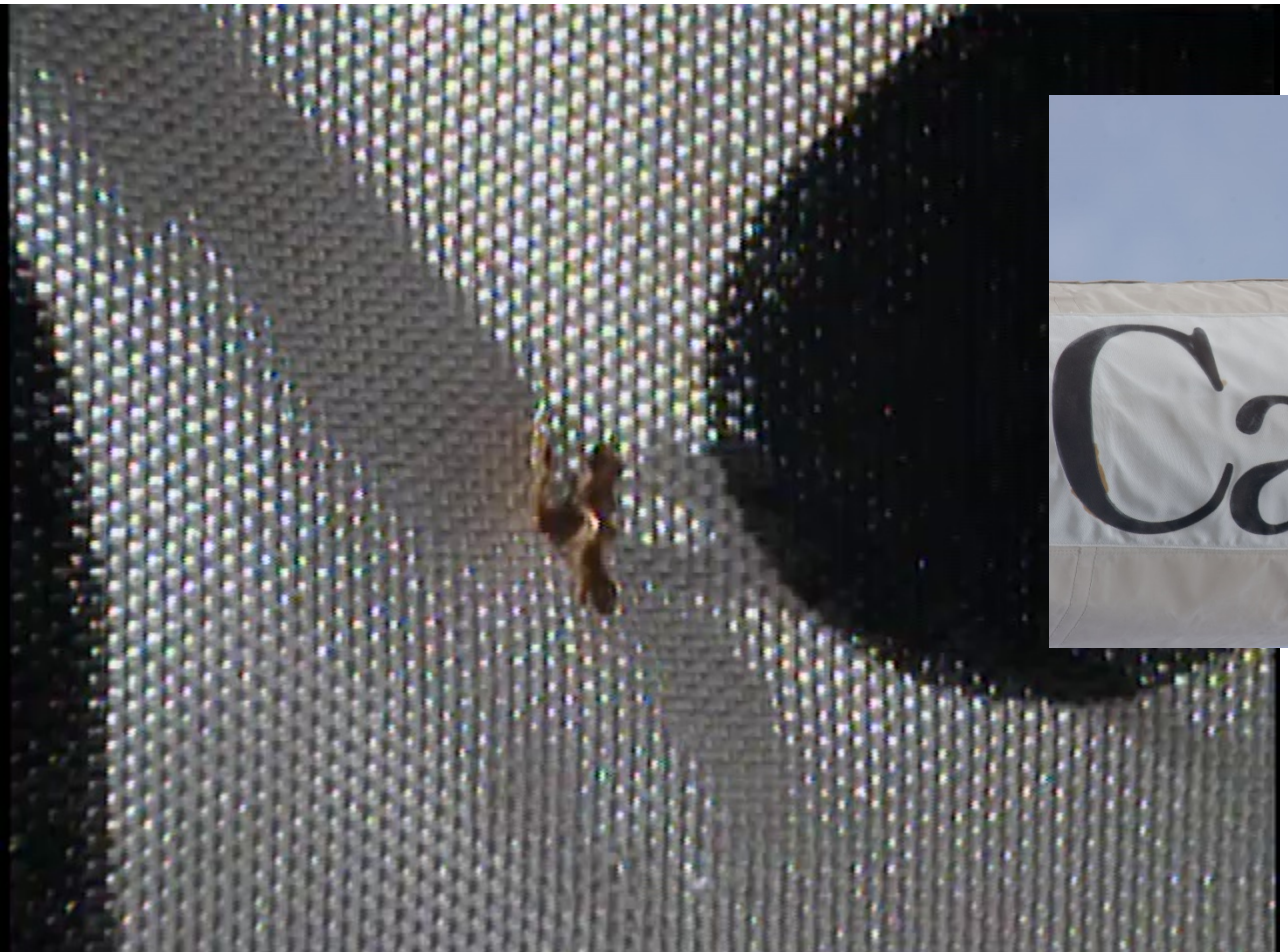
Space Station Remote Manipulator System (SSRMS)

Possible MMOD strike on SSRMS, close-up image obtained 9 Oct 2015



Backup Charts

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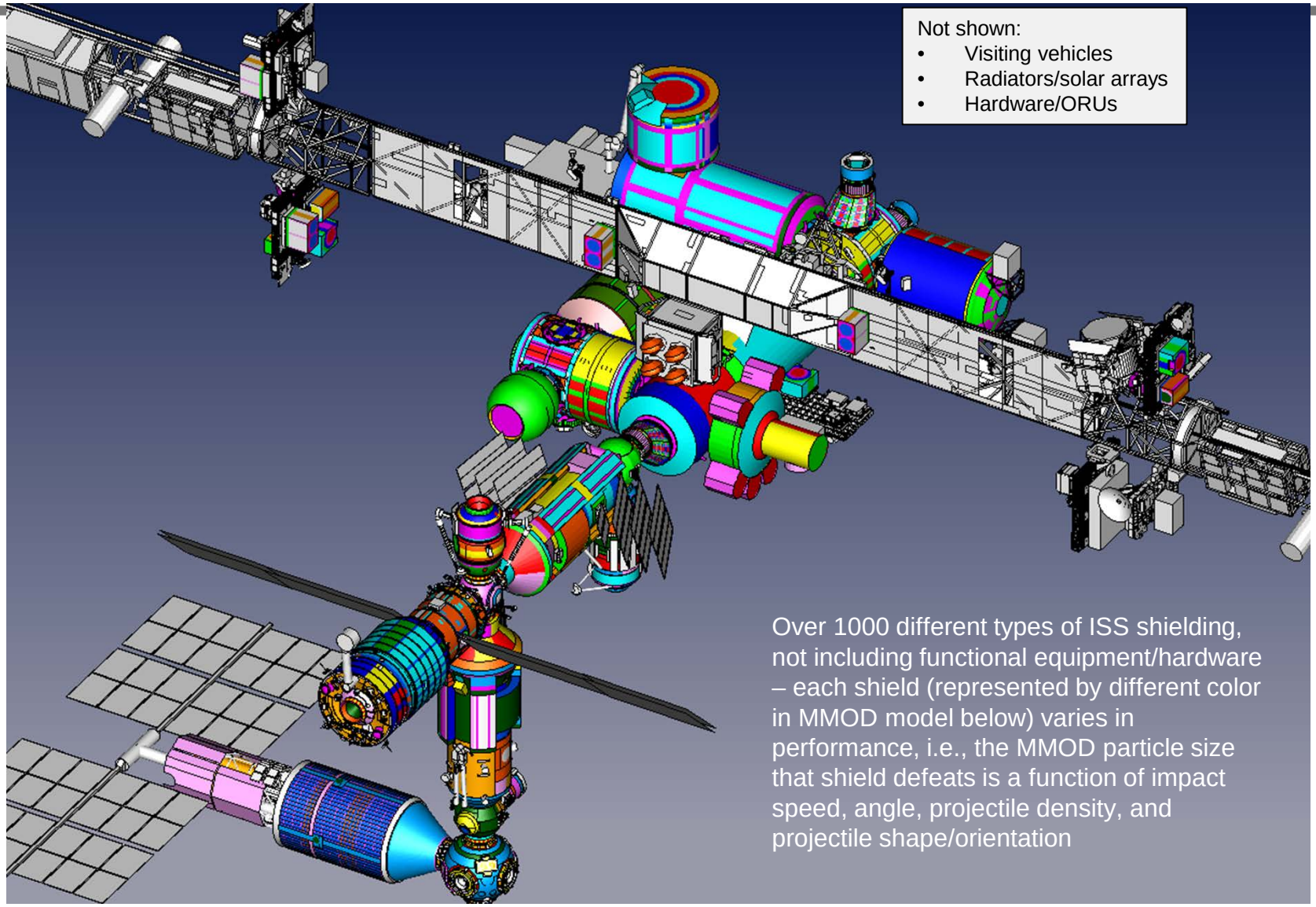
ISS *Bumper* finite element model

after addition of MLM, Russian Node, Science Power Module, and Bigelow Expandable Activity Module (BEAM), and after PMM relocation



Over 1000 different types of ISS shielding, not including functional equipment/hardware – each shield (represented by different color in MMOD model below) varies in performance, i.e., the MMOD particle size that shield defeats is a function of impact speed, angle, projectile density, and projectile shape/orientation