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Orion Artemis I As Flown MMOD Analysis

2nd International Orbital Debris Conference

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12/5/2023

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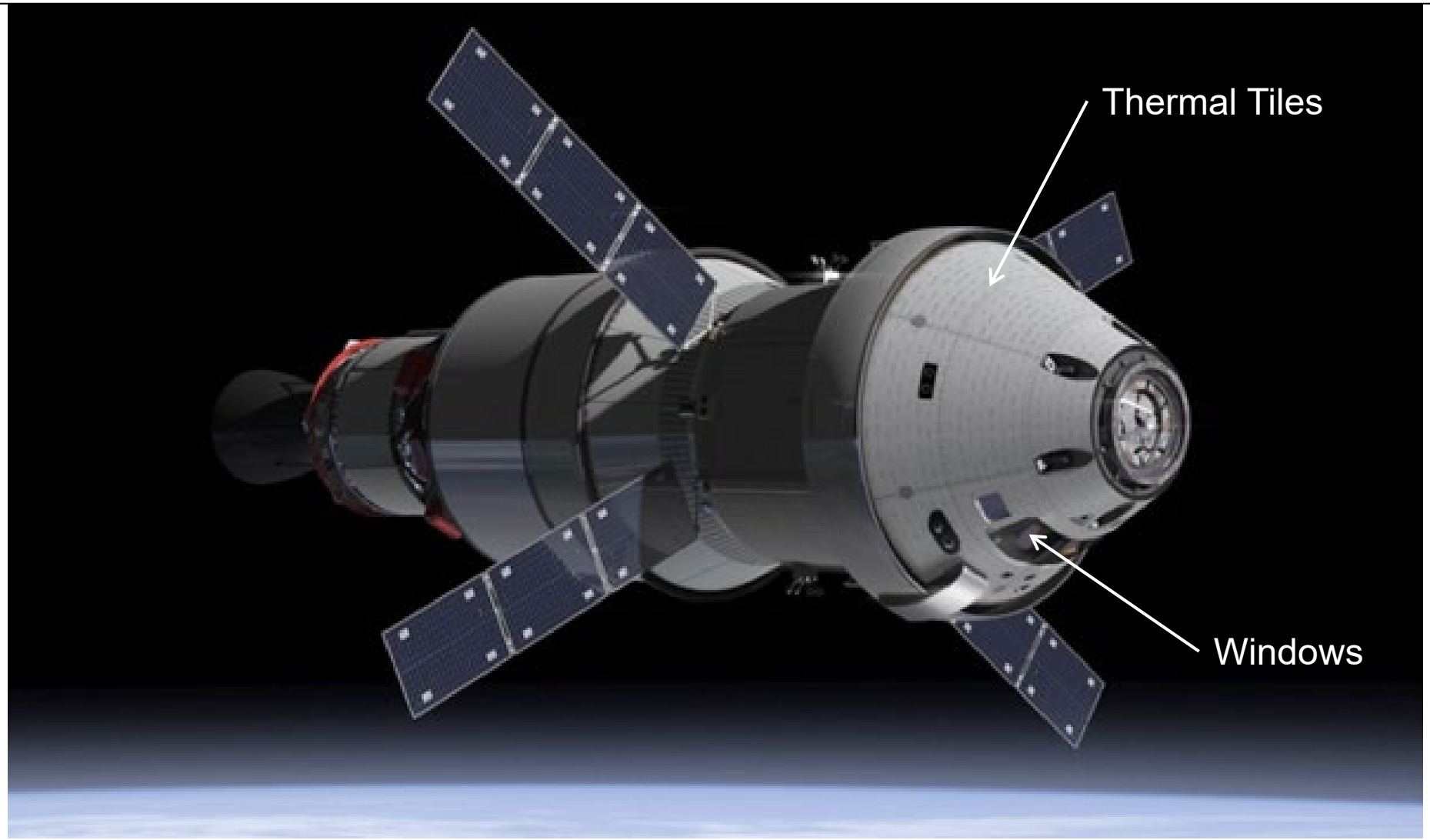
Orion Spacecraft

Orion will provide more recording area to collect small impacts than has ever been flown into deep space before



Bumper Analysis

- The Bumper analysis software was employed to calculate the number of damages of various sizes expected to be caused by MMOD
- Environment models used:
  - ORDEM 3.2
  - MEM 3
    - 2022 Meteoroid Shower Forecast included
- Ballistic limit equations translate environment model impactors into damage size

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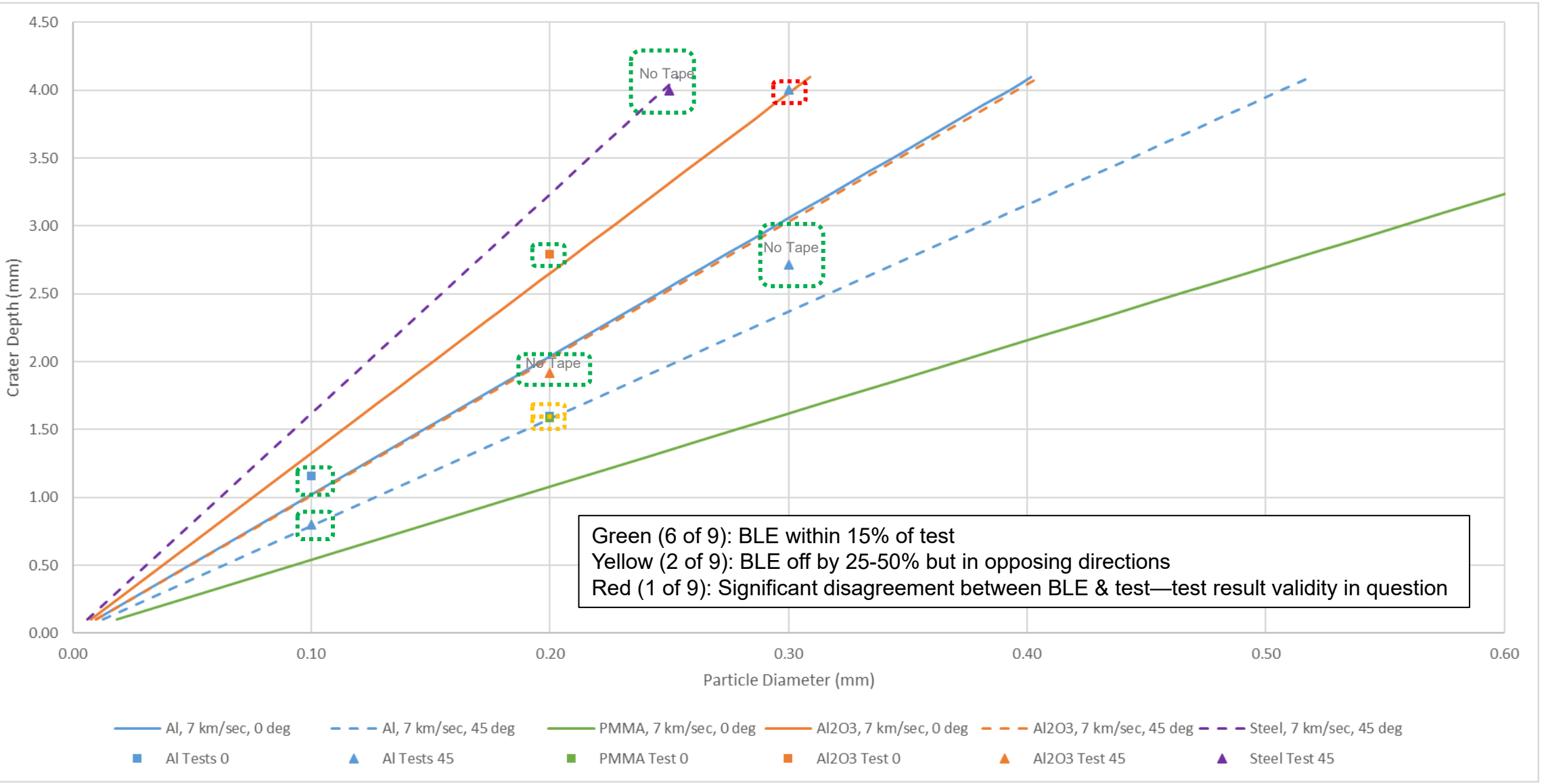
Ballistic Limit Equation: Small Crater in Thermal Tile



Post-Flight Inspection

- Primary post-flight inspection of thermal tile & main windows conducted at Kennedy Space Center, January 24-25, 2023
  - Multiple inspections of various portions of the capsule conducted as opening became available
- Thermal tiles bonded to substrate panels that had been removed from the vehicle
- Pieces of reflective tape remained on the tiles
  - Tape mostly burned off during reentry

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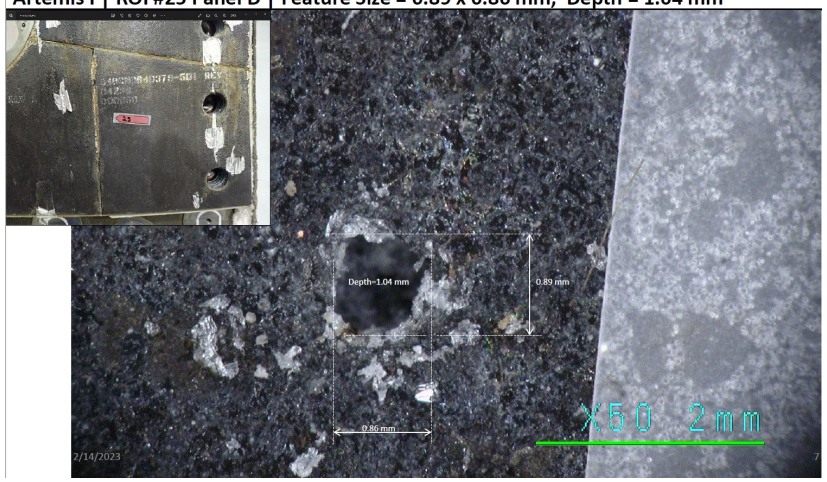
Regions of Interest on Thermal Tile

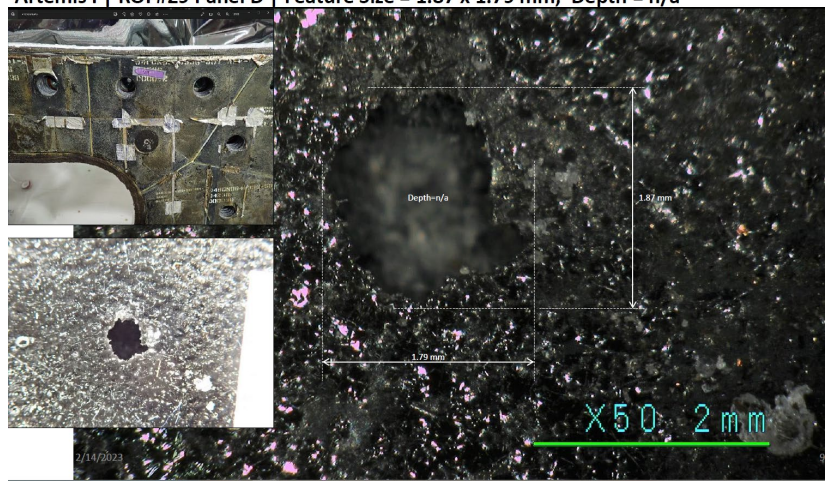
Artemis I | ROI #25 Panel D | Feature Size = 0.89 x 0.86 mm, Depth = 1.04 mm



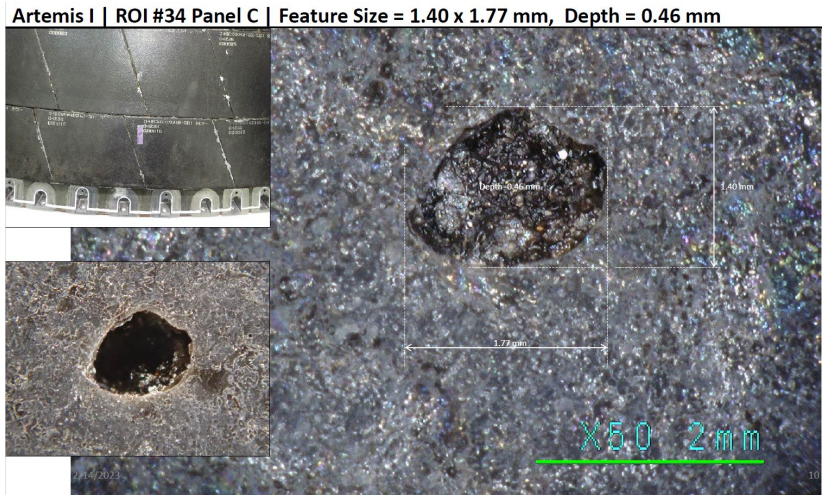
Five potential MMOD impact sites in the thermal tiles were identified and preliminarily characterized

Further laboratory characterization is planned

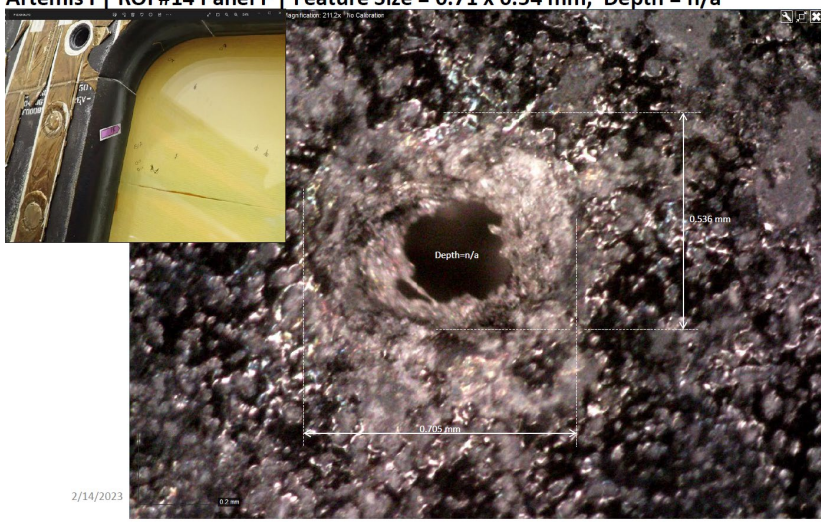
Artemis I | ROI #29 Panel D | Feature Size = 1.87 x 1.79 mm, Depth = n/a



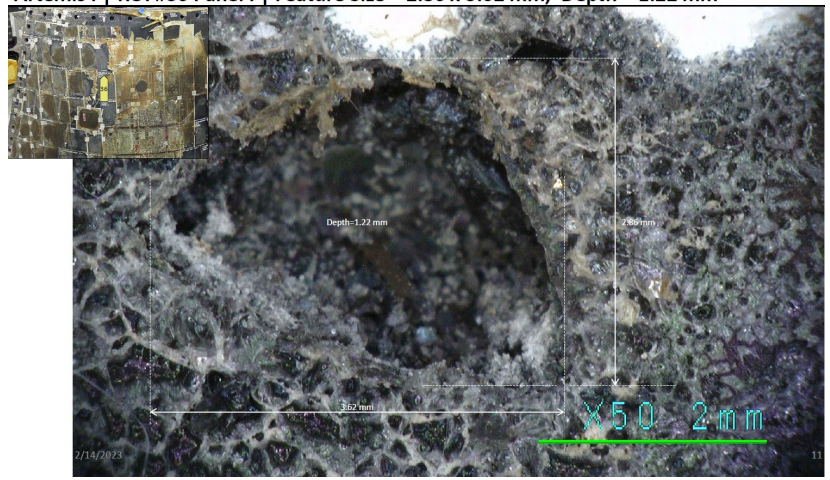
Artemis I | ROI #34 Panel C | Feature Size = 1.40 x 1.77 mm, Depth = 0.46 mm



Artemis I | ROI #14 Panel F | Feature Size = 0.71 x 0.54 mm, Depth = n/a



Artemis I | ROI #36 Panel I | Feature Size = 2.86 x 3.62 mm, Depth = 1.22 mm



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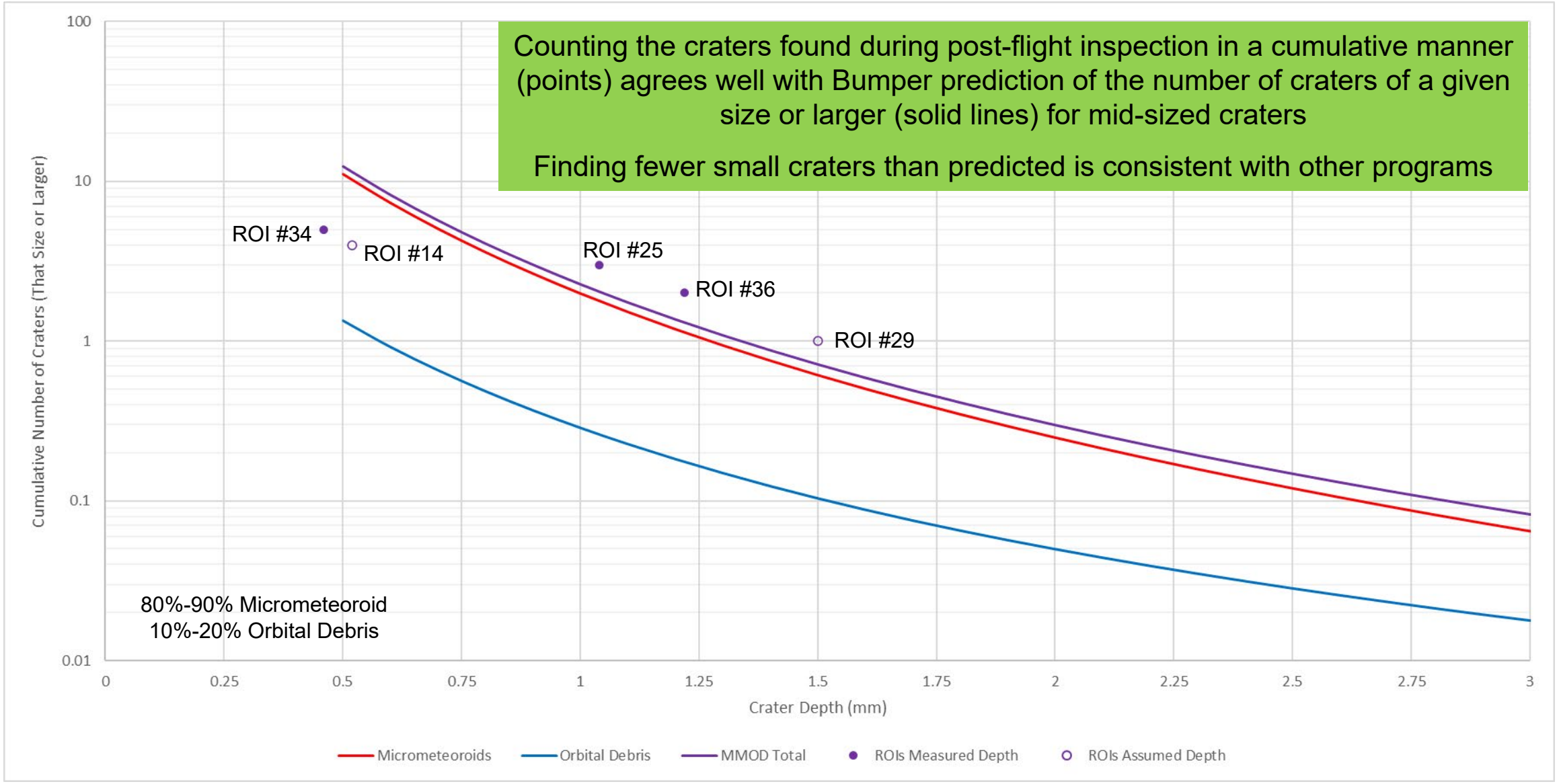
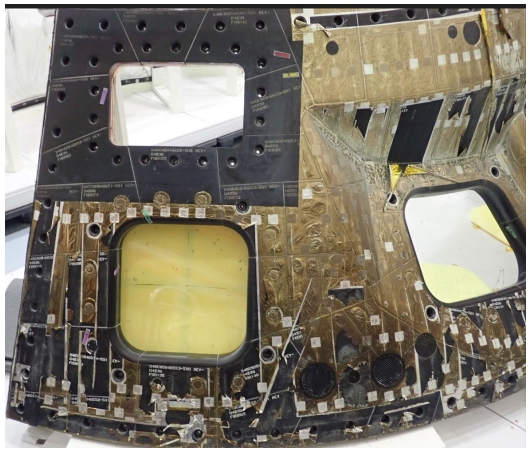
Thermal Tile As-Flown vs. Post-Flight Inspection



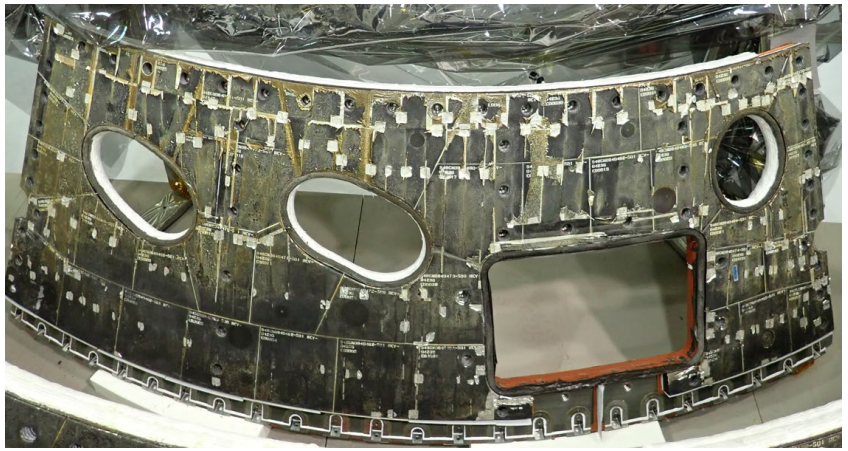
Remaining Tape

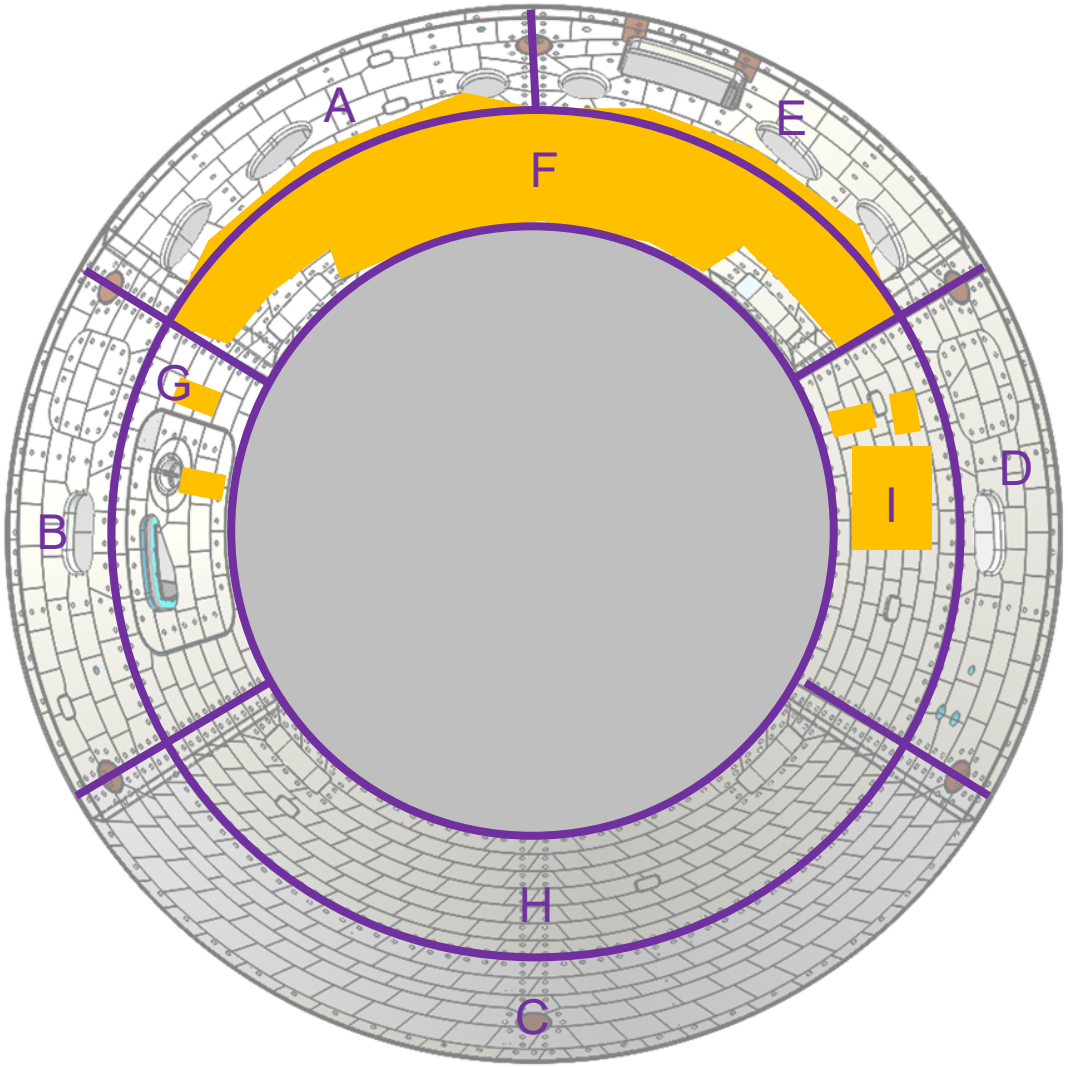
- Reflective tape was applied to the thermal tiles to achieve various desired properties for the flight
- Most of the tape burned off during reentry
- Some tape remained, especially on Panel F, where the main windows are located
  - Scattered small squares of tape remained across the whole capsule (shown on Panel E)
- A Bumper analysis was performed to calculate the number of tape damages expected to be caused by MMOD
  - Analysis included adjustment for how much tape remained

Panel F



Panel E





Tape Damage

- Tape prediction consistent with findings
  - Most of tape burned off → only 18% of predicted impacts are on remaining tape
- Expected to find 2 holes on Panel F, found 1 ROI
  - Most complete panel
- Expected 1 more ROI across vehicle, found it on Panel D
  - Panel I would have been more likely due to more remaining tape

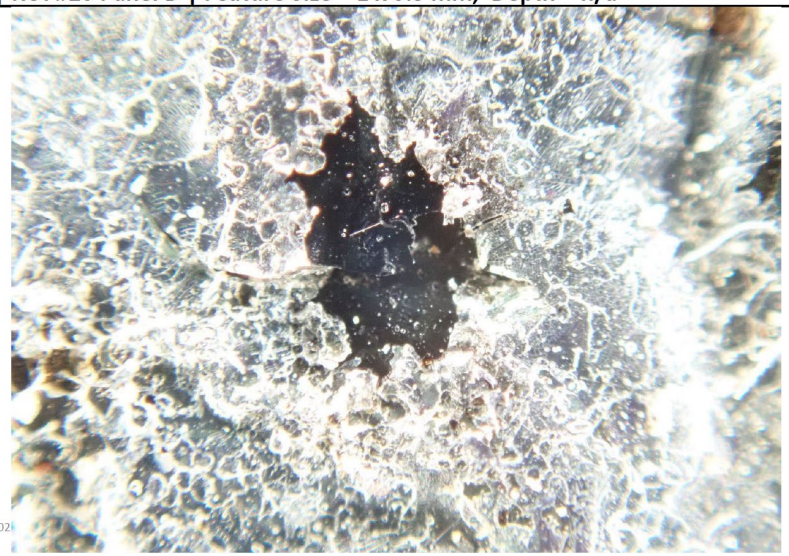
Location	Full Panel Number of Tape Holes	Remaining Tape	Adjusted Number of Tape Holes
Panel A	1.59	10%	0.16
Panel B	2.01	5%	0.10
Panel C	3.63	2%	0.07
Panel D	1.11	5%	0.06
Panel E	1.05	7.5%	0.08
Panel F	2.87	70%	2.01
Panel G	1.05	10%	0.10
Side Hatch	0.86	5%	0.04
Panel H	3.56	5%	0.18
Panel I	1.15	40%	0.46
Total	18.88		3.41

Found 2 ROIs

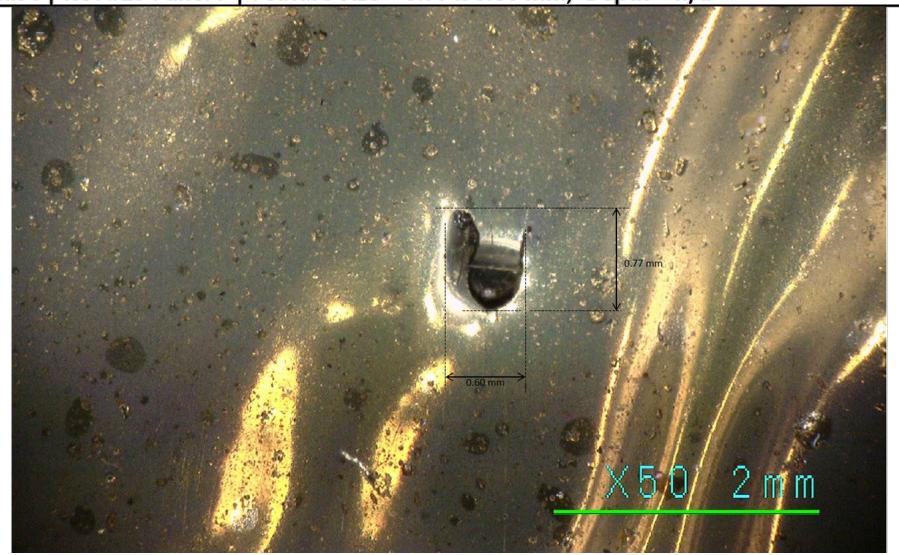
Found 1 ROI

Found 1 ROI

Artemis I | ROI #26 Panel D | Feature Size ≈ 1 x 0.5 mm, Depth = n/a

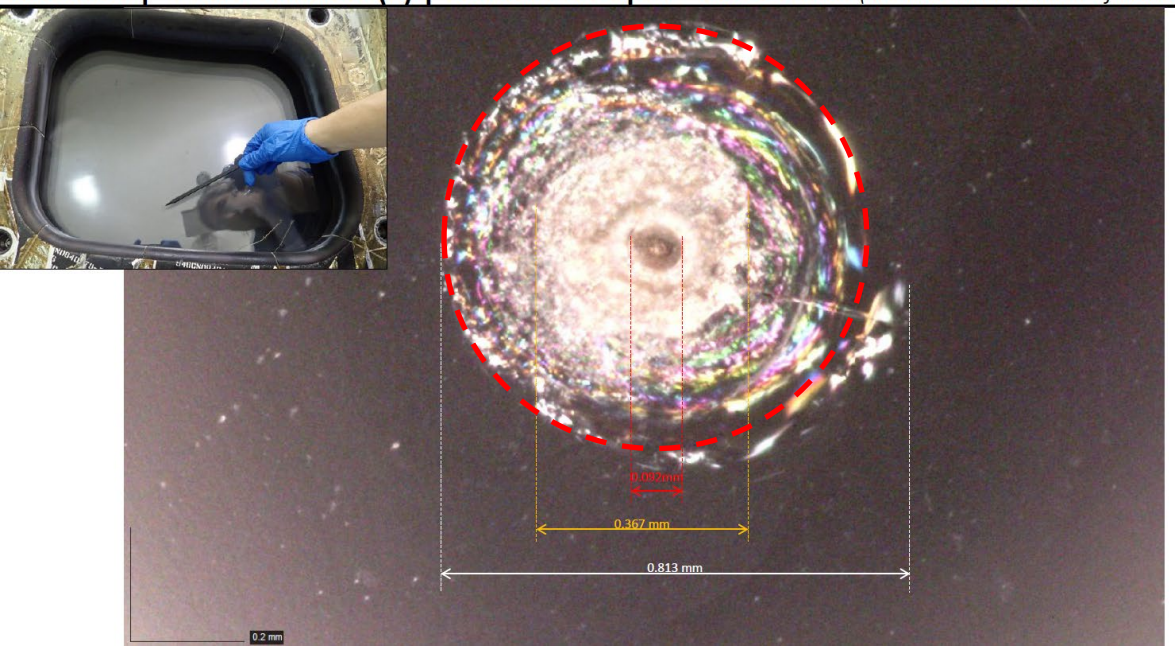


Artemis I | ROI #13 Panel F | Feature Size = 0.77 x 0.60 mm, Depth = n/a



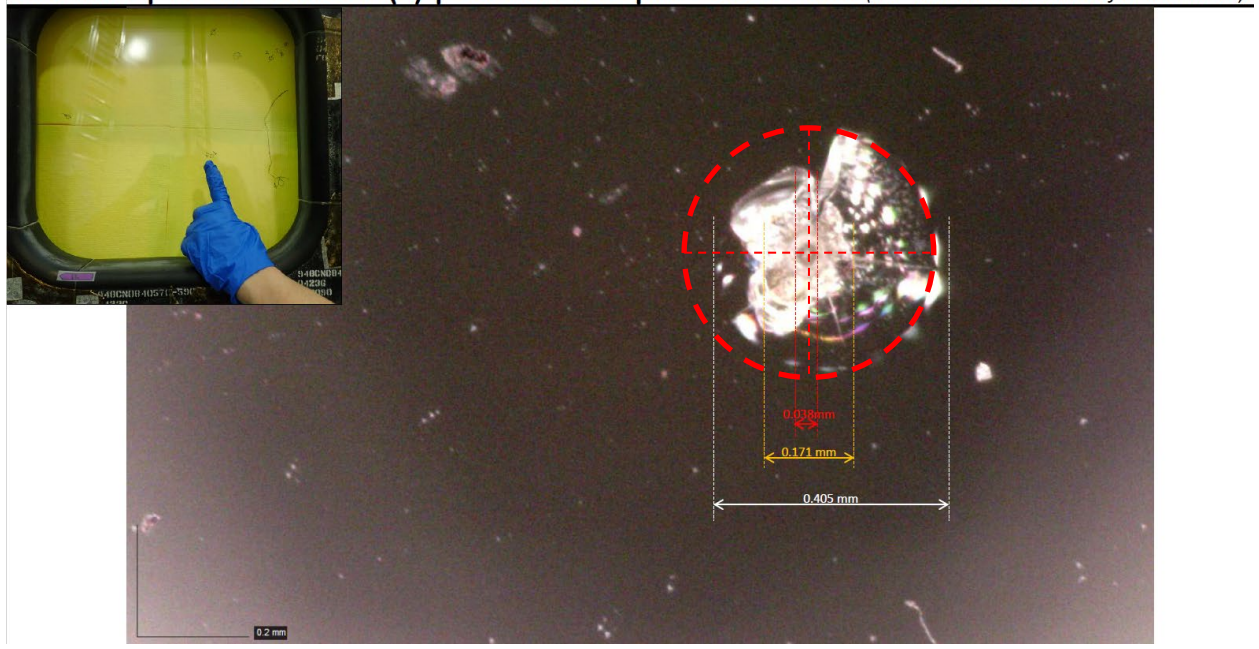
Window ROIs

Artemis I | -Y Fwd Window (1) | Central Pit Depth = 0.0356 mm *(KSC MIT measurement of dental mold)*



Diameter = 0.730 mm

Artemis I | +Y Side Window (2) | Central Pit Depth = 0.0279 mm *(KSC MIT measurement of dental mold)*



Diameter = 0.428 mm

Based on radius determined from maximum glass damage

Assumption: impact obliquity or other factors artificially clipped extent of damage in some directions

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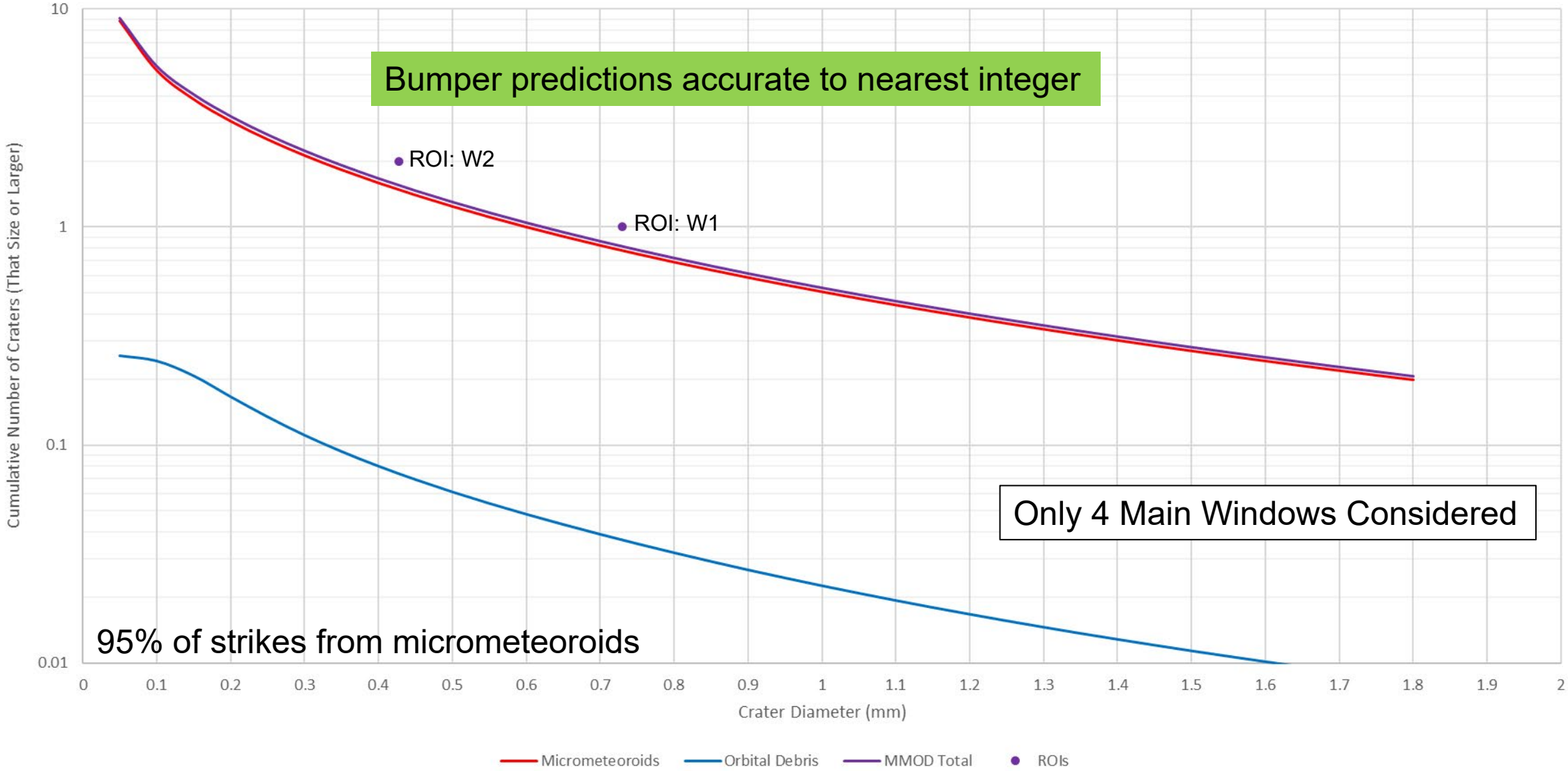
Window Comparison



Summary

- NASA inspected the Orion capsule for possible MMOD damage and, separately, a Bumper risk assessment was performed to predict the number of craters expected to be found
  - Similar to past programs
- Comparison of Prediction to Findings
  - Backshell Tile
    - 5 potential MMOD craters were found
    - Prediction of crater numbers matches well with inspection findings for depths > 1 mm
      - Shallower craters: Bumper predicted more craters than were found, which is consistent with historical trends and may be explained by the difficulty in finding very small craters
    - Extraction of the five potential MMOD damage site tiles is in work to provide more data to improve this assessment
  - Backshell Tape
    - 2 holes in the remaining reflective tape were found and may have been caused by MMOD
    - Prediction of hole numbers (3.4 holes) consistent with inspection finding
      - Predicted ;ocations of holes consistent with inspection finding
  - Windows
    - 2 potential MMOD craters were found in the main windows
    - Prediction of crater numbers matches well with inspection findings for diameters > 0.5 mm
      - Smaller craters: Bumper predicted more craters than were found, which is consistent with historical trends and may be explained by the difficulty in finding very small craters
- Conclusions
  - These comparisons demonstrate a high degree of accuracy in Bumper risk assessment
  - The inspection findings will aid future refinement of environment models to improve accuracy still further