Mount Etna, Italy
Landsat 8 / OLI (bands 4-3-2) & TIRS
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Landsat 9 Micrometeoroid Orbital Debris (MMOD) Mission Success Approach

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Agenda

- **Problem Definition – Why assess against Mission Success?**
- **Solution Process**
- **Environment Assessment**
- **Characterize Threat**
- **Generate Design Curves**
- **Exceptions**
- **Lessons Learned**
- **Summary**

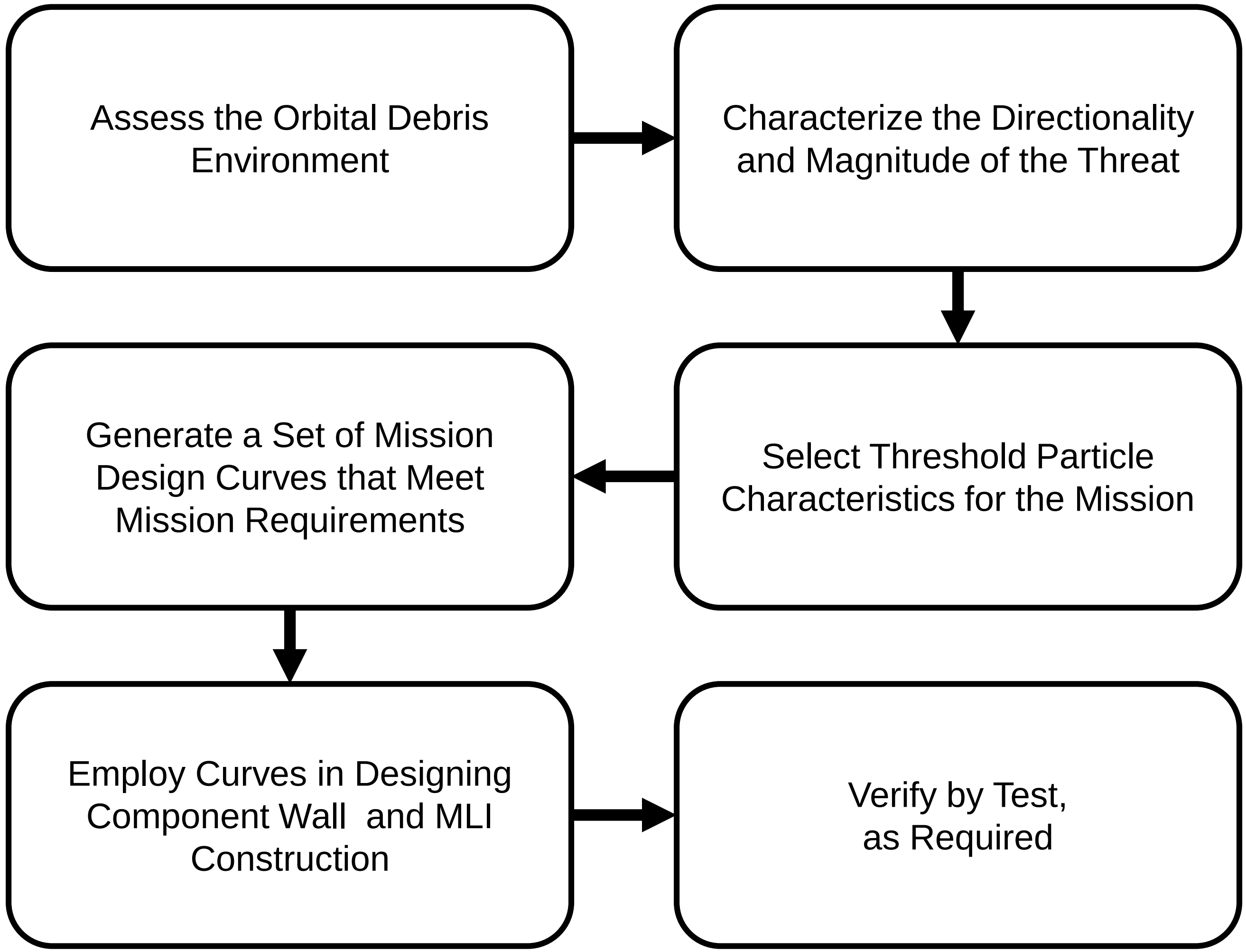
The Problem

- **NASA-STD 8719.14B addresses only reentry critical hardware and generation of new orbital debris**

- **Mission success requires 2-3 times as much hardware on robotic missions to meet Level 1 science requirements**
  - Additional hardware required for assessment includes radiators, instruments, data storage, communication, Attitude Control System (ACS) hardware

- **Why not assess these items and protect billion dollar missions against the risk from MMOD?**

The Solution Process



Environment Assessment

- **Use the latest version of ORDEM for Orbital Debris and MEMR for micrometeorites**
- **Calculate spacecraft cross-sectional areas, known orientations, and planned mission durations in each orientation** (Nominal, Safehold, Reboost, etc.)
  - Vast majority of time spent in Nominal orientation
- **Assuming the probability of a single impact for the mission, find the projected particle size for the given flux curve**
  - Based on acceptable risk of a penetration
  - When looking at protection designs, the longest duration orientation will most likely drive design

Particle Selection from Flux Curve

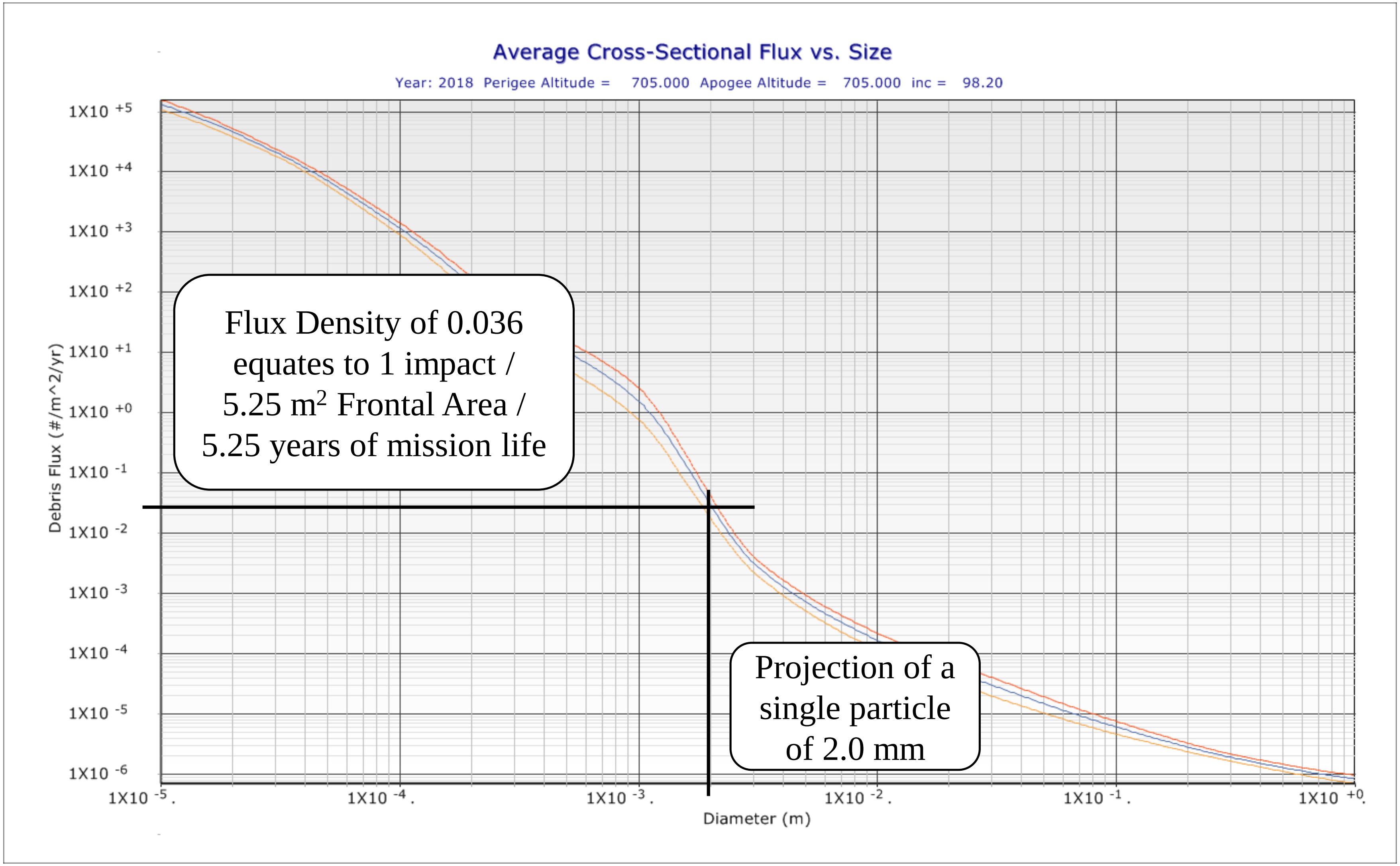


Figure 1. Omnidirectional Orbital Debris Flux Curve for the Landsat 9 Orbit

Characterize Threat Directionality, Speed, & Density

- **Landsat 9 OD environment (705 km, 98.2 deg) was examined in order to determine the relative threat from each direction.**
- **ORDEM 3 predicted flux values were examined for 1 mm and 3.16 mm fiducial points, medium density and high density particles**
  - Principle spacecraft directions were assessed (Nadir was essentially nil)
  - Ram dominates the directionality of the particles
- **Medium density (2.8 g/cm3) particles dominate the flux predictions**
  - High density (7.9 g/cm3) particles constituting only about 10% of the total flux
  - Other particles types predicted by ORDEM 3 had negligible flux
- **The ORDEM 3 also provides average velocity.**

Table 1 - Directional Orbital Debris Flux and Velocity for the Landsat 9 Orbit

	1 mm Fiducial			**3.16 mm Fiducial**		
↓Direction	Total Flux $[\#/(m^2 * yr)]$	% Flux	Avg. Vel. (km/s)	Total Flux $[\#/(m^2 * yr)]$	% Flux	Avg. Vel. (km/s)
Port	1.34E-02	2.3%	7.89	3.23E-05	3.8%	7.99
Ram	**5.53E-01**	**95.4%**	**14.69**	**7.77E-04**	**92.3%**	**14.70**
Starboard	1.34E-02	2.3%	7.89	3.23E-05	3.8%	7.99
Wake	2.24E-07	0.0%	0.80	6.49E-09	0.0%	0.58
Zenith	3.02E-07	0.0%	0.50	1.82E-09	0.0%	0.50
Total	5.80E-01			8.42E-04		

Generate Design Curves

- **Manned missions designs have relatively thick shield, typically used to protect thick pressure walls**
- **Robotic spacecraft designs employ thinner shields to protect thin walled electronic boxes**
- **The bumper thickness, wall thickness, and separation between MLI and structure were analyzed iteratively until a protection threshold was achieved for the given particle size.**
  - Reimerdes Ballistic Limit Equation (BLE) was used for initial designs
  - Other parameters were held constant throughout the assessment: Al particles (2.8 g/cm^3) at 14.7 km/s and 0^o impact angle, and Aluminum 7075-T6 wall material
- **The design curves indicate the minimum set of conditions to prevent penetration by a 2 mm medium density particle**
- **There is a minimum effective component wall thickness, below which enhancing the blanket density is no longer an effective strategy (the blanket/bumper becomes the dominant shield)**

Design Curves for Protection against Penetration of 2 mm, 14.7 km/s, Medium Density Particles

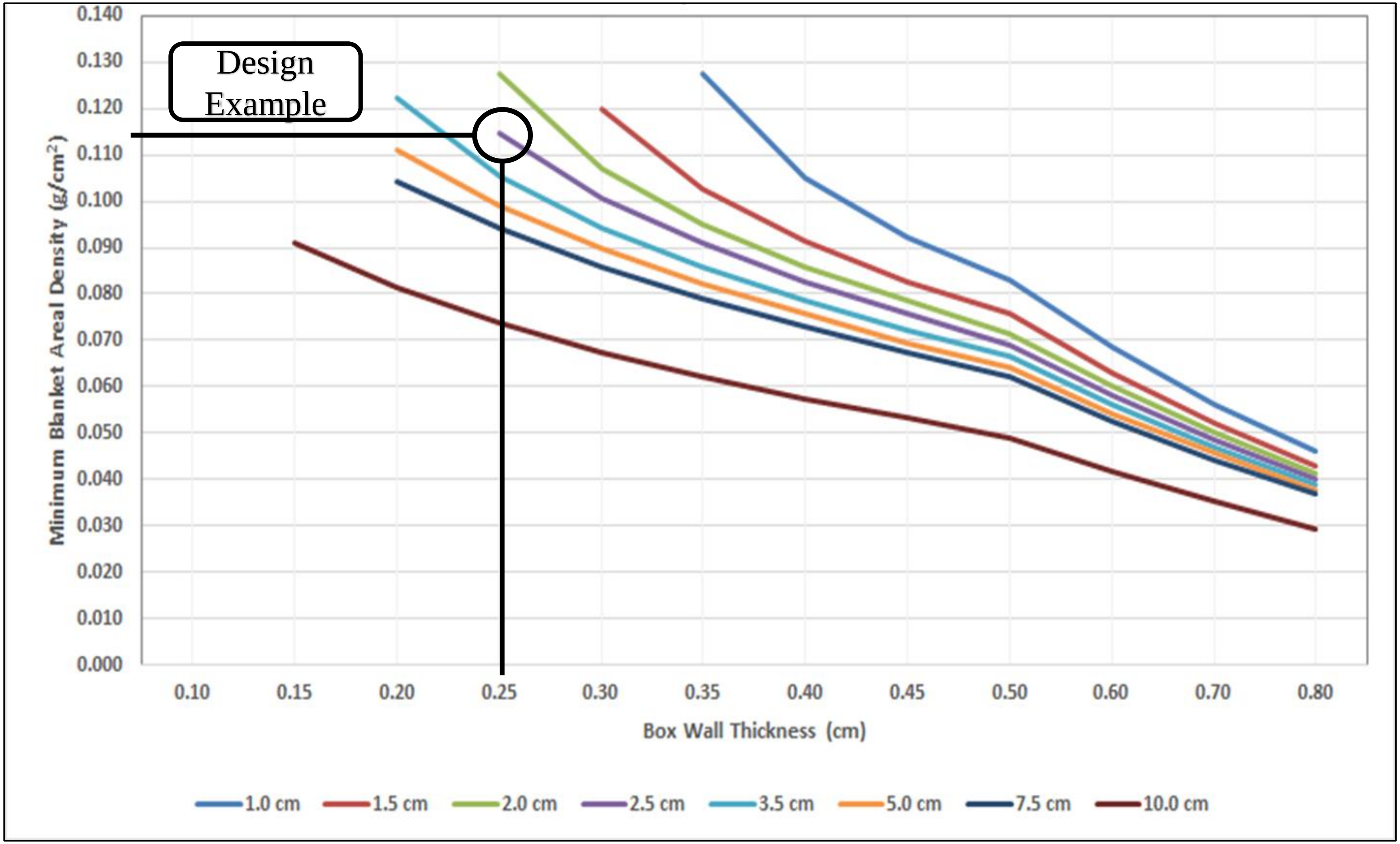


Figure 2. Design Curves for Protection against Penetration of 2 mm 14.7 km/s particles

Exceptions to Mission Success MMOD Req'ts

- **Exempted items:**
  - Antennas
  - Optical Apertures
  - Thermal (radiator) Apertures
  - Solar Array
  - Thruster Apertures
  - Mechanisms
  - Redundant Harnesses (physically separated)
- **When the protection is for unique hardware (see list above), then it is more difficult to provide generic design guidelines.**
  - These items require point solution and involve heavy analysis and/or testing (especially for unique materials).
  - Often, additional analysis was performed to quantify the risk.
- **While there was no overall probability of success target, the analysis provided a quantitative assessment when assessing risk from penetration versus protection implementation complexity**

Lessons Learned

- **Engage the Subject Matter Experts at the HyperVelocity Technology Team (HVIT) early for help with modeling and analysis**
- **Model all Spacecraft components (both Reentry Critical and Mission Success) in Bumper to improve protection results and to provide a quantitative risk assessment**
- **Assess MMOD risk early enough that there is still time to incorporate changes based on analysis results**
  - Overall layout of components on the SC
  - Physical construction of components (box-wall thickness, radiator surface, etc.)
- **Plan for a test program**
- **There are multiple ways to apply redundancy to lower risks**
- **Assess for all orientations in mission timelines. Some short durations operations can still be a design driver.**
- **Verify material data sheets from vendors**

Summary

- **The overall Landsat 9 assessment of including Mission Success MMOD requirements for the mission was positive.**

- **Given that the instruments are located in the ram direction and facing the brunt of the MMOD flux, added shielding should yield a better return on investment with a greater probability of meeting Level 1 science goals.**

- **There is always room for improvement and the future areas of focus will be on the items that were exempted previously listed.**

- **Given the increased knowledge of the mission systems team, the next Landsat mission will have a better understanding of MMOD design mitigations that can be incorporated into the observatory layout earlier in the design phase.**

- **Shielding in the primary MMOD flux direction will have a higher priority when considering placing critical science instruments in harm’s way.**