# Landsat 9 Micrometeoroid and Orbital Debris (MMOD) Mission Success Approach

**Michael S. Pryzby[(1)], Scott M. Hull[(2)], Angela M. Russo[(2)], Glenn T. Iona[(2)], and Evan H. Webb[(2)]**

[(1)] ATA Aerospace, 7474 Greenway Center Dr, Suite 500, Greenbelt, MD 20770, USA
[(2)] NASA Goddard Space Flight Center, 8800 Greenbelt Rd, Greenbelt, MD 20771, USA

ABSTRACT

Landsat 9* (L9) is the successor mission to Landsat 8 (L8) previously known as Landsat Data Continuity Mission (LDCM). Both missions are large unmanned remote sensing satellites operating in sunsynchronous polar orbits. As opposed to L8/LDCM, systems engineers for L9 incorporated Micrometeoroid/Orbital Debris (MMOD) protection for small object collisions as part of the L9's mission success criteria. In other words, the NASA Process for Limiting Orbital Debris (NASA-STD-8719.14A) only calls for analyses of the protection of disposal-critical hardware, but L9 opted to also assess and provide small particle penetration protections for all observatory components including instruments that are not part of the spacecraft components needed for controlled reentry.

Systems engineers at Goddard developed a design process to protect against MMOD during the life of Low Earth Orbit (LEO) observatories, and in particular the Landsat 9 Mission. Simply stated, this design process enhanced the effectiveness of existing Multi-Layer Insulation (MLI) to provide the needed protection.

The end goal of the design process was to establish a necessary blanket areal density for a given electronics box or instrument wall thickness and a separation between the outer MLI blanket and the structure underneath. The trade space was presented as a set of design curves for different combinations of blanket density, box wall thickness, and separation distance between MLI and structure.

An advantage of this process was that it is largely independent of MMOD flux data on a surface-by surface basis. Ultimately, cost savings should result from incorporating small object penetration protection early in the design cycle, rather than adding spot shielding blankets later as needed to meet an overall penetration risk standard (the more traditional approach). The approach and implementation to the L9 Observatory design will be addressed in this paper.

*L9 is a joint mission being formulated, implemented, and operated by the National Aeronautics and Space Administration (NASA) and the Department of the Interior's (DOI) United States Geological Survey (USGS).

## 1 Introduction

Like all NASA Earth-orbiting missions, Landsat 9 addresses MMOD risks as required by NASA Standard NASA-STD-8719.14. This approach focuses on limiting orbital debris by either the generation of debris or leaving space borne assets in orbit past mission life. These requirements focus on components with stored energy (explosive risks) and re-entry critical components (safe removal of assets from useful orbits.)

Given the inclusion of millions of dollars of science instruments, it seems logical that assessments should be made on behalf of MMOD for all mission success related components (non-reentry critical components) as well. Mission success components include, but are not limited to, science instruments, high data rate communications, and data storage components. Landsat 9 has taken the novel approach to address MMOD mitigation requirements for all mission success components, in addition to those needed for responsible disposal.

On Landsat 9, the instruments (OLI-2 and TIRS-2) are both mounted on an instrument deck facing into the ram direction. Given that this is the worst case orientation for MMOD flux, the Landsat 9 Mission Systems Engineering team implemented a design criteria to address some protection for these components.

NASA/GSFC Systems Engineering Branch has developed a design process to protect against MMOD for mission success components during the life of Low Earth Orbit (LEO) observatories, and in particular the Landsat 9 Mission. This design approach enhances the effectiveness of existing Multi-Layer Insulation (MLI) to provide the additional protection needed. There are three ways to improving the effectiveness of the MLI blanket:

1) Increase the areal density (g/cm$^2$) of the MLI;
2) Provide separation between the MLI and the critical surface underneath, and;
3) Selectively incorporate ceramic fabric and Kevlar® layers in the design.

This design approach is to develop a dual use functionality for the current thermal protection systems that uses MLI.

## 2 Approach

The end goal is to establish a necessary blanket areal density for a given box or instrument wall thickness and the separation between the outer MLI blanket and the structure underneath. The trade space is presented as a set of design curves for different combinations of blanket density, box wall thickness and separation distance between MLI and structure.

Functionally, the approach consists of five steps followed by verifications by test as may be required:

1) Examining the expected orbital debris environment;
2) Characterizing the directionality and velocity components of the debris environment;
3) Selecting threshold particle characteristics for each major spacecraft direction;
4) Establishing a set of curves to define the minimum acceptable shielding design, and;
5) Employing those curves in the design of components and MLI blankets;
6) Verify by test, as required.

This process for estimating the probability of penetration for as-designed constructions is illustrated in Figure 1.

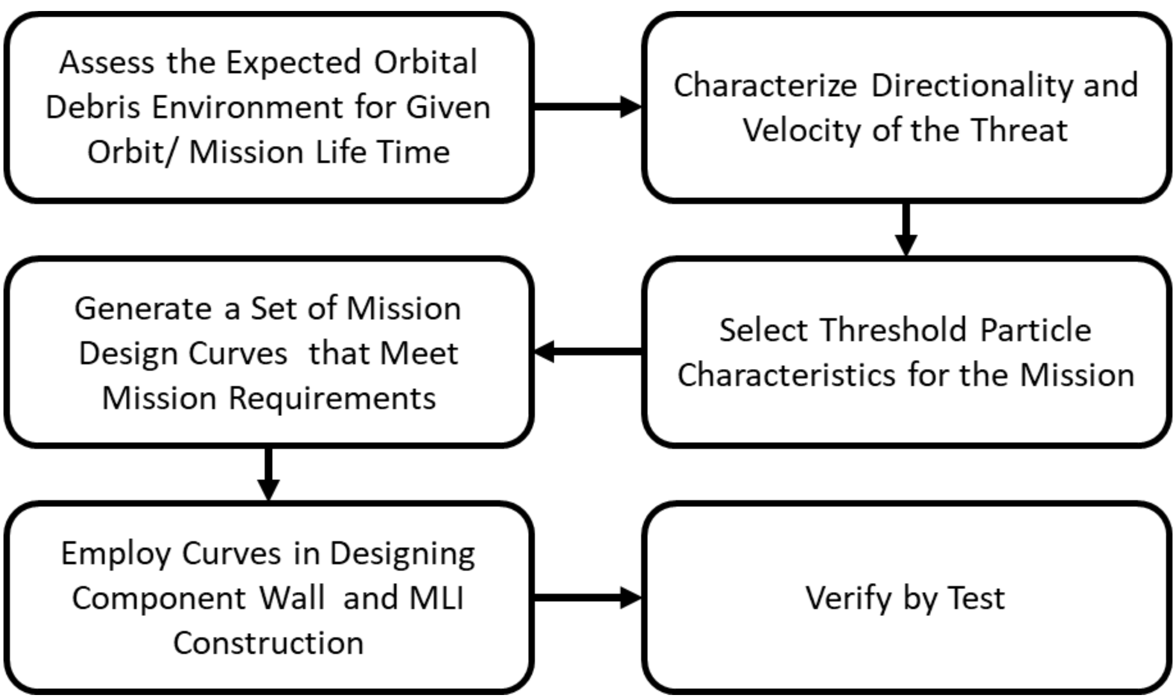


**Figure 1. Overall Description of the Proposed Process**

An advantage of this technique is that it is largely independent of MMOD flux data on a surface-by-surface basis. Ultimately, cost savings should result from incorporating small object penetration protection early in the design cycle, rather than adding spot shielding blankets later as needed to meet an overall penetration risk standard.

## 3 Omnidirectional Flux Comparisons

The NASA Orbital Debris Engineering Model (ORDEM), version 3.0 orbital debris flux model, was used for this exercise. This model predicts the flux of particles in several categories, including medium density (essentially aluminum) and high density (essentially stainless steel). Meteoroid flux was neglected, since it is typically far lower than orbital debris flux in LEO orbits. Figure 2 shows the total flux (omnidirectional) versus particle size for the Landsat 9 orbit in 2018 (yellow and orange lines are +/- 1 sigma). A mission lifetime requirement of 5.25 years and an assumed cross-sectional area for the observatory of approximately 5.25 m$^2$ are assumed. The design assumption is that a single penetration is mission critical. Critically, we note from Figure 2 that protection is required for 2mm particles and smaller.

ORDEM 3.0 was used to estimate the relative omnidirectional flux for each particle size. The next stage of the work examined the effect of directionality on this potential improvement.

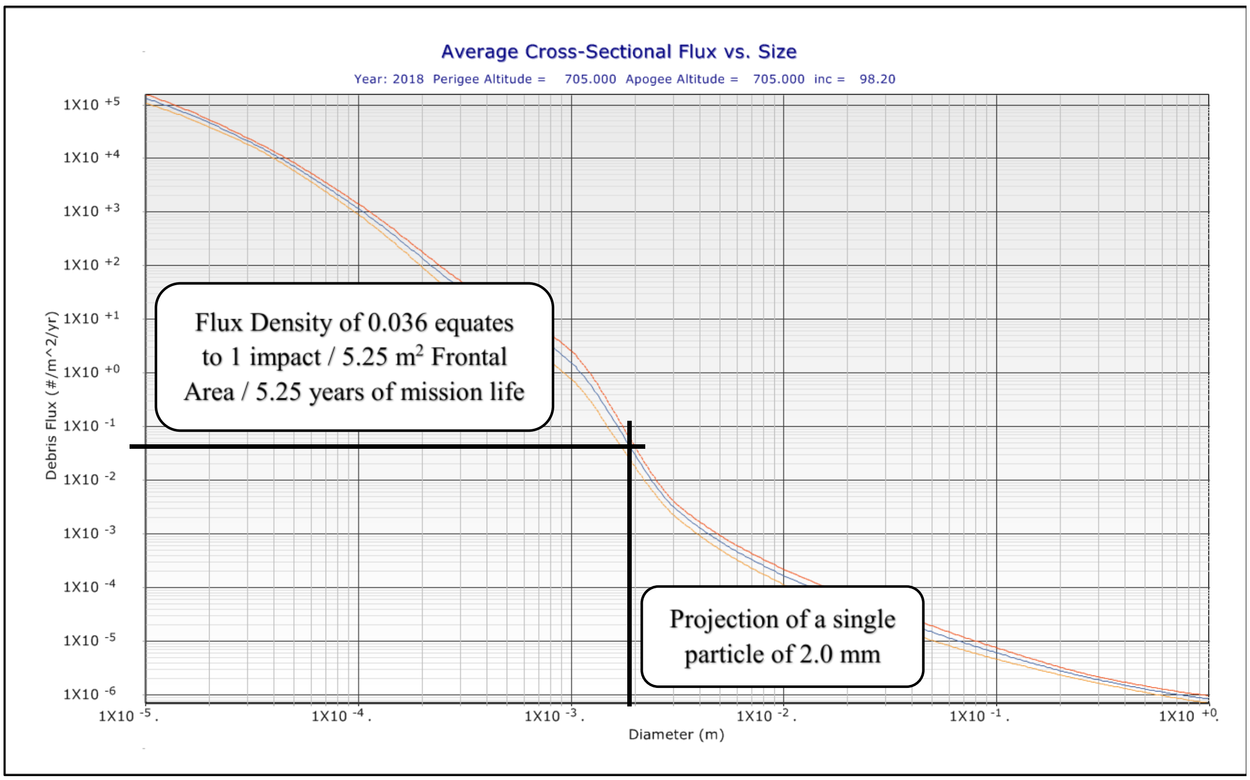


**Figure 2. Omnidirectional Orbital Debris Flux Curve for the Landsat 9 Orbit**

## 4 Directionality of the Threat

ORDEM 3.0 generates a histogram plot to indicate the directionality of the orbital debris flux independent for particle size, shown in Figure 3. This plot simply indicates that the majority of the orbital debris impacts the spacecraft in the velocity, or 'ram', direction.

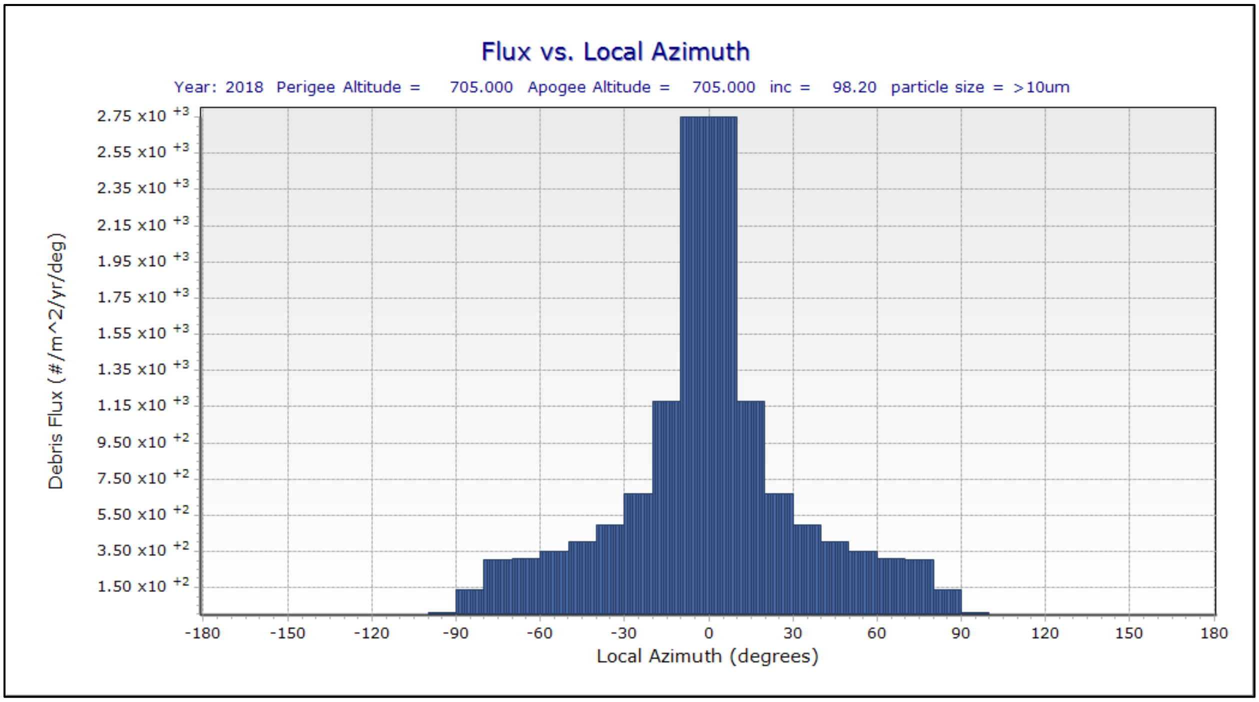


**Figure 3. Directionality of the Orbital Debris Threat to Landsat 9**

The specific Landsat 9 orbital debris environment 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, in five of the six principle spacecraft directions (ram, port, starboard, wake, and zenith); the threat from nadir direction is essentially nil. The ORDEM 3 flux output values are also presented by velocity, in 1 km/s bins, allowing calculation of an average velocity. Medium density (2.8 g/cm$^3$) particles dominate the flux predictions at 705 km, 98.2°, with high density (7.9 g/cm$^3$) particles constituting only about 10% of the total flux; other particles types predicted by ORDEM 3 had negligible flux.

Table 1 presents the relative flux and average velocity for particles potentially striking the spacecraft from each of five directions.

**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 | | |

## 5 <u>Shielding Design Plots</u>

Penetrating particle size is a function of a number of parameters, and can be estimated using established Ballistic Limit Equations, determined over decades of hypervelocity impact testing by the Hypervelocity Impact Technology (HVIT) group at NASA/JSC. The bulk of the testing done to date has been performed in support of manned missions, where relatively thick shields are typically used to protect thick pressure walls. Far less data has been generated for the robotic spacecraft design scenarios, where thinner shields protect relatively thin electronics box walls. As a result, fairly well accepted two-wall Whipple shield equations (also known as bumper shields) exist, but those equations are less applicable to robotic spacecraft. For robotic spacecraft designs that employ thin shields, there is an approach proposed by Reimerdes (and generally accepted by the community) to essentially interpolate between a fully effective bumper layer and a shield that is effectively the same as just a slightly thicker box wall (no benefit in breaking up the particle).

A particle size of 2 mm was selected as the penetrating particle size for shielding for the Landsat 9 mission, as described above. Penetration thresholds were calculated using the Shield Ballistic Limit Analysis Program (SBLA) Excel Add-in supplied by JSC/ HVIT group, which includes the Reimerdes modification for thin-wall bumpers. The bumper thickness, wall thickness, and separation between MLI and structure were adjusted iteratively until a protection threshold was achieved for the given particle size. Other parameters were held constant throughout the assessment: Al particles (2.8 g/cm$^3$) at 14.7 km/s and 0° impact angle, and Aluminum 7075-T6 wall material. A set of curves for 2 mm particle protection is shown in Figure 4.

The design curves in Figure 4 indicate the minimum set of conditions (component wall thickness, blanket density, and separation distance) to prevent penetration by a 2 mm particle, as indicated by the SBLA for the parameters described above. The information is repeated numerically in Table 2 for reference. As a design example, if a component has an aluminum wall 0.100" thick (0.25 cm), and the MLI blanket is to be located 2.5 cm from the component wall, the blanket must have an areal density of at least 0.115 g/cm$^2$ in order to prevent penetration. Alternatively, if the blanket spacing can be increased, equivalent protection could be achieved with a thinner, lighter blanket. As shown in Figure 4, there is a minimum effective component wall thickness, below which enhancing the blanket density is no longer an effective strategy (until the blanket/bumper becomes the dominant shield, a case that was not considered here).

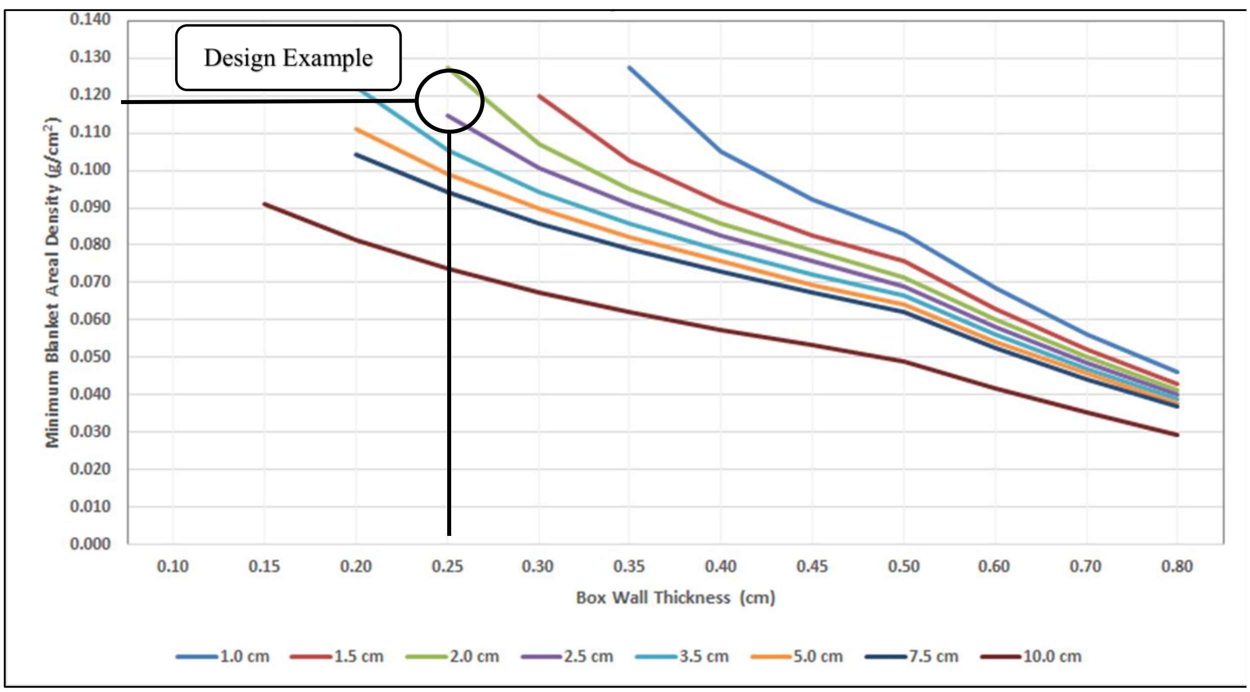


**Figure 4. Design Curves for Protection against Penetration of 2 mm 14.7 km/s particles**

**Table 2. Numerical Values for the Data Plotted in Figure 4.**

| | Blanket Areal Density (g/cm$^2$) at a Given Wall Thickness (cm) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **S (cm)** | **0.10** | **0.15** | **0.20** | **0.25** | **0.30** | **0.35** | **0.40** | **0.45** | **0.50** | **0.60** | **0.70** | **0.80** |
| **1.0** | | | | | | 0.127 | 0.105 | 0.092 | 0.083 | 0.069 | 0.056 | 0.046 |
| **1.5** | | | | | 0.120 | 0.103 | 0.092 | 0.083 | 0.076 | 0.063 | 0.052 | 0.043 |
| **2.0** | | | | 0.127 | 0.107 | 0.095 | 0.086 | 0.078 | 0.071 | 0.060 | 0.050 | 0.041 |
| **2.5** | | | | 0.115 | 0.101 | 0.091 | 0.083 | 0.076 | 0.069 | 0.058 | 0.049 | 0.040 |
| **3.5** | | | 0.122 | 0.105 | 0.094 | 0.086 | 0.078 | 0.072 | 0.066 | 0.056 | 0.047 | 0.039 |
| **5.0** | | | 0.111 | 0.099 | 0.090 | 0.082 | 0.076 | 0.069 | 0.064 | 0.054 | 0.046 | 0.038 |
| **7.5** | | | 0.104 | 0.094 | 0.086 | 0.079 | 0.073 | 0.067 | 0.062 | 0.053 | 0.044 | 0.037 |
| **10.0** | | 0.091 | 0.081 | 0.074 | 0.067 | 0.062 | 0.057 | 0.053 | 0.049 | 0.042 | 0.035 | 0.029 |

## 6 Enhancements to MLI Design

Extending the use of MLI blankets from just a thermal barrier to MMOD protection seems a natural extension of the sub-systems use in spacecraft design. By adding two additional materials to a typical MLI blanket design it is possible to significantly increase its physical protection effectiveness. The design trades presented above do not directly incorporate the use of these materials. The MLI blanket areal density does not take the material properties of the bumper material into account. Using Kevlar or Nomex near the inner layer (essentially in contact with the box wall) provides a weight-efficient means of increasing the effective box wall thickness. Though no empirical data is available for the use of ceramic fabrics, like Nextel™, near the outer most layer of an MLI blanket design, it is known to improve shield performance because it is better at breaking up projectile fragments. On the other hand, Kevlar®, when mounted to the rear wall, improves shield performance by trapping the resulting debris cloud expansion.

## 7 Exceptions to the Mission Success Requirements

Landsat 9 did allow for some exceptions to the mission success requirements. Those items are antennae, optical apertures, thermal (radiator) apertures, solar array, thruster apertures, mechanisms, and redundant harnesses that are physically separated from each other. The primary requirements and curves provided above are relevant for most electronics boxes and walled components. When the protection is for unique hardware like optical surfaces (solar arrays) thermal radiator surfaces, non-metallic materials (antenna), 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). As L9 delved into this new set of requirements for mission success, the unique hardware set above was exempted at the discretion of the Mission Systems Engineer. 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.

## 8 Summary and Look Ahead

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, the project having required, designed, and assessed the protection for MMOD will yield a better return on investment with a greater probability of meeting Level 1 science goals. There is always room for improvement and the areas of focus will be on the items that were exempted above. 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.