PROPULSION & SPACE ENVIRONMENTS

T3 ORBITAL FLOWSAT

CAL POLY Aerospace Engineering

Astronautics Senior Design 2023-2024
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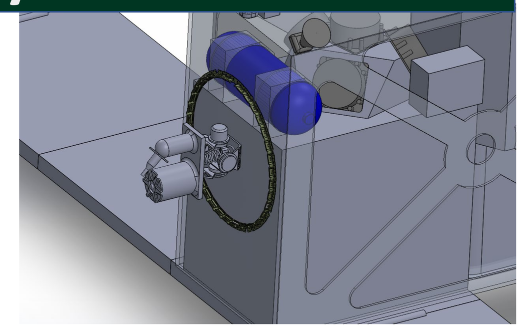
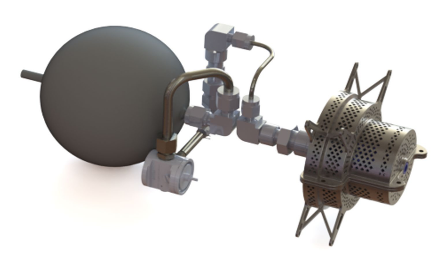
Designed System

Dry Mass: 4.85 kg
Propellant Mass: 12.15 kg
Thrust: 13 mN



Propellant Feed System x1

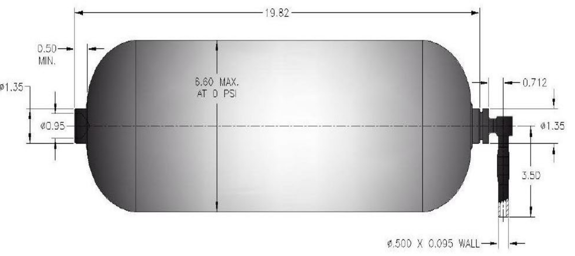
SETS Prop. Feed System
Mass: 1.1 kg
Size: $145 \times 127 \times 118\ mm$
Mass Flow rate: $0 - 3.5 mg/s$



[1]

Propellant Tank x1

ARDE 4898
Tank Volume: 8.28 L
Tank Mass: 2.77 kg
Pressure Range: $0 - 16\ MPa$
Temp Range: 0 – 60℃



[2]

Thruster x1

BHT-200
Mass: 0.98 kg
Power: 200 W
Thrust: 13 mN
ISP: 1390 s
Propellant Type: Xenon

[3]

Plume Characteristics

Neutral Density (m^{-3})

Anode Flow: 0.897 mg/s
Cathode Flow: 0.135 mg/s

Main Beam Ions (m^{-3})

Exit Velocity: 13.6 km/s

Total Ion Density (m^{-3})

- Shows some depositing behind thrust
- Minimal amounts

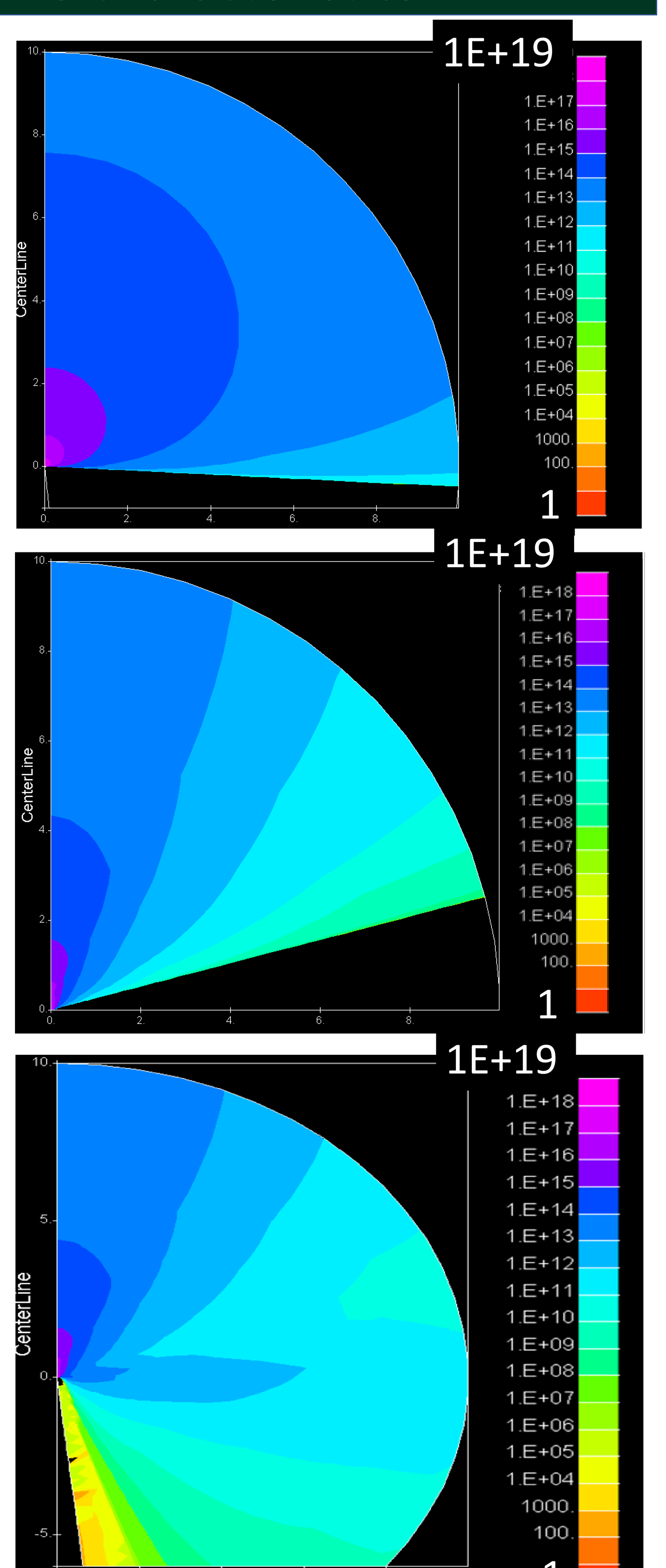
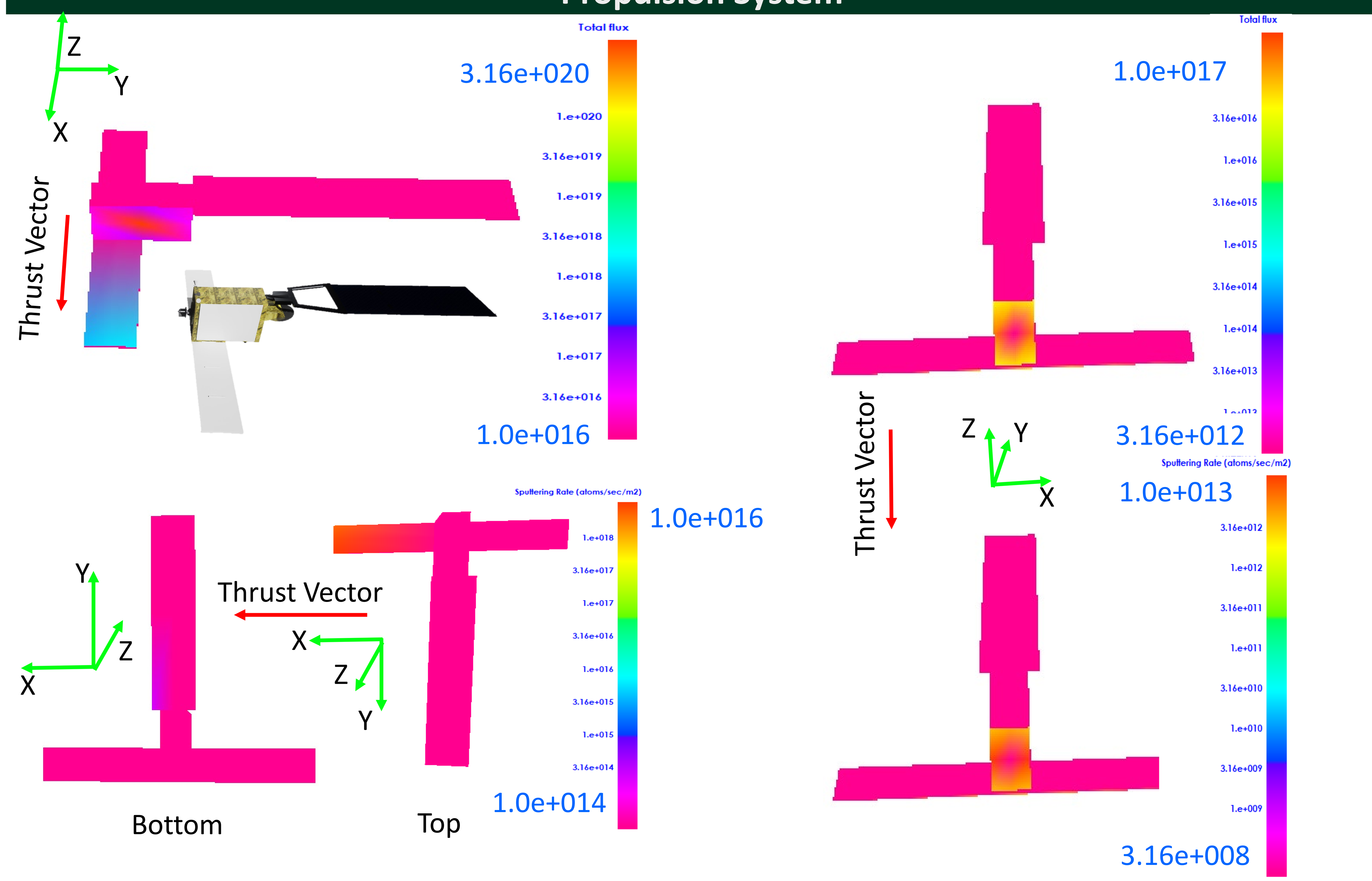


Figure 1: Particle Density of Plume.

Propulsion System



1st iteration: Thruster Vector Parallel to SAR

Final Iteration: Thrust Vector Perpendicular to SAR

Figure 2: Total Flux and Sputtering rate due to thruster.

Sensor Contamination from Outgassing Species

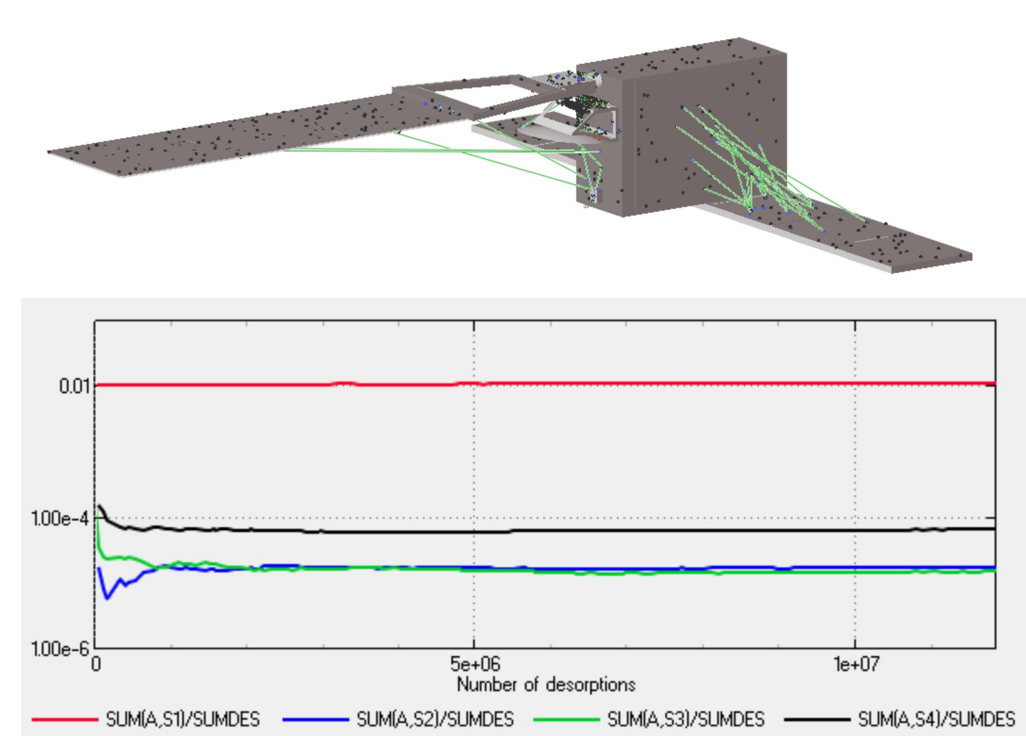


Figure 3: Transport factor to optical payloads, ext.*

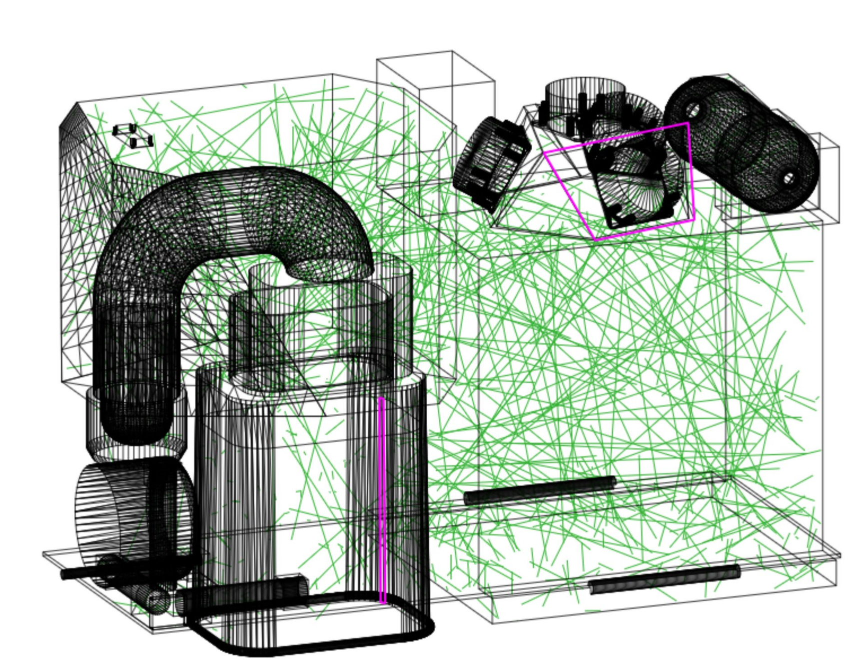


*Figure 4: Interior Outgassing Species Analysis**

*Table 1: External Outgassing Species Analysis**

Parameter	Name	Value
Total Absorption	Payload instruments	140654
Total Desorption	All surfaces	$1.18434e + 07$
Transport Factor	PMWR Reflector	$\mathbf{0.0117694}$
Transport Factor	PMWR Sensor 1	$\mathbf{1.85758e - 05}$
Transport Factor	PMWR Sensor 2	$\mathbf{1.63805e - 05}$
Transport Factor	MSI	$\mathbf{7.18546e - 05}$

*Table 2: Interior Outgassing Species Analysis**

Parameter	Name	Value
Total Absorption	Payload internals	$6.39865\ e + 06$
Total Desorption	All internal surfaces	$6.84659\ e + 06$
Transport Factor	MSI	$\mathbf{0.138232}$

*Monte Carlo ray tracing analysis using Molflow+

Atomic Oxygen Erosion

$$number\ density_{700\ km}:\ n_{AO} = 4.22 \times 10^7\ \frac{atoms}{cm^3}\ [4]$$

Table 3. AO Parameters and Calculations

	Parameter	Kapton	Z-93 White Paint
RAM Area	$A\ [m^2]$	0.29	1.14
Density [3]	$\rho\ [g/cm^3]$	1.45	1.5
AO Velocity	$v\ [km/s]$	7.5	7.5
Erosion Yield [1, 4]	$E\left[\frac{cm^3}{AO\ atom}\right]$	$3\ e - 24$	$0.4\ e - 24$
Erosion Rate [1]	$\frac{dx}{dt} = nvE$	$0.071\frac{mm}{yr}$	$0.0095\frac{mm}{yr}$
Erosion Depth [1]	$d = \frac{dx}{dt}t$	$\mathbf{0.355\ mm}$	$\mathbf{0.047\ mm}$
Mass Loss [1]	$dm = \rho A \frac{dx}{dt} dt$	$149.2\ g$	$20.58\ g$

Mission time, t, is 5 years. Erosion depth of Z-93 is less than the thickness of the Z-93 on the radiator (0.127 mm) so the **paint will last mission lifetime**. Erosion depth of Kapton is 3x greater than the thickness of a single Kapton layer on the MLI (~ 0.127 mm). This will result in a **loss of 3 MLI layers** in the RAM direction. However, the spacecraft thermal system was modelled to keep the bus at 9°C. Further analysis is required, but it is assumed that the **temperature will remain nominal** despite AO degradation.

MMOD and Shielding

Probability of no penetration [6]: $\text{PNP} = e^{-FAt}$

$\mathbf{PNP_{tot}} = \mathbf{95.12}\%$, $\text{PNP}_{tot_{sp,normal,ram}} = 92.1\%$

Where F = 2 mm particle flux and A = RAM area

Table 4. PNCF For Components Seen in RAM Direction

Part	PNCF
Radiator	96.09%
Sensors	95.51%
Star Trackers	99.97%
Comm Antenna	99.93%
Prop System	99.76%
Solar Panels (side in RAM)	99.58
Solar Panels (top in RAM)	89.56%

The maximum particle diameter that can be withstood by an aluminum monolithic shield is given by: [5]

$$d_c = \left(\frac{t}{k} \frac{BHN^{0.25} \left(\rho_p / \rho_t \right)^{0.5}}{5.24 \left(v\ cos\theta / C_t \right)^{\frac{2}{3}}} \right)^{\frac{18}{19}}$$

Where t = shield thickness, k = damage parameter, BHN = Brinell hardness number, ρ_t = target density, ρ_p = particle density, v = particle velocity, θ = impact angle, and C_t = speed of sound in target.

This requires that a monolithic shield to be 1.02 cm thick to protect from 2 mm diameter particles in the RAM direction. Shielding in every other direction is not needed, because the PNP only increases as you move away from the RAM face.

The **radiator** acts as a Whipple shield, **which will protect against 3.4 mm diameter particles.** No additional shielding is needed behind the radiator.