ThinkOrbital Electron Beam Multi-Function Test Flight-2 Demisability Report

TO-0210

Think Orbital

March 1, 2023

Revision	Date	Section/Page	Author	Change Summary
R0	March 1, 2024	All	F. Tybor	Initial Release
R1	Aug 5, 2024	Multiple	F. Tybor	Changes with mission to Bandwagon 2, added drag structure for de-orbit within 5 years due to change in de-orbit time requirement for launches post 30 Sep 24. Minor reduction in mass with elimination of components.
R2	9/24/2024		F. Tybor	Added Drag area discussion section. Inclusion of final as built and weighed mass.
R3	10/17/2024		F. Tybor	Revised to 12/29/24 Launch Date. Weight updated in DAS analysis after payload weigh in.

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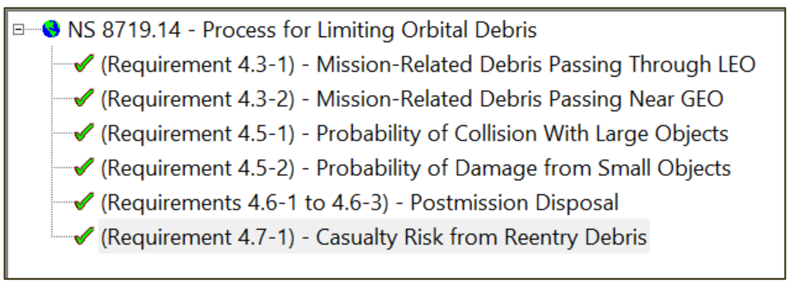
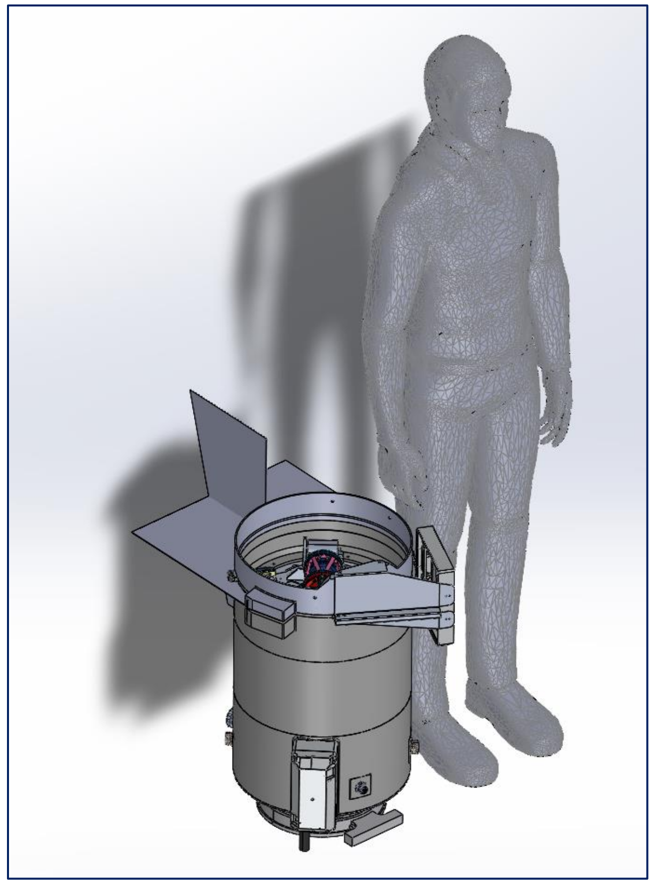
Executive Summary

The Electron Beam Multi-Function Test Flight-2 consists of a single, 39.4 kg as-built and weighed, R2D2-sized cylinder with a 510 km orbit at 45.4 Deg Orbital inclination. ThinkOrbital Flight-2 will de-orbit passively, with an expected lifetime of 4.5 years. The payload was analyzed using the NASA Debris Assessment Software (DAS), version 3.2.5, and was found to be in compliance with all requirements, and fully demisable per NASA-STD-8719.14C.

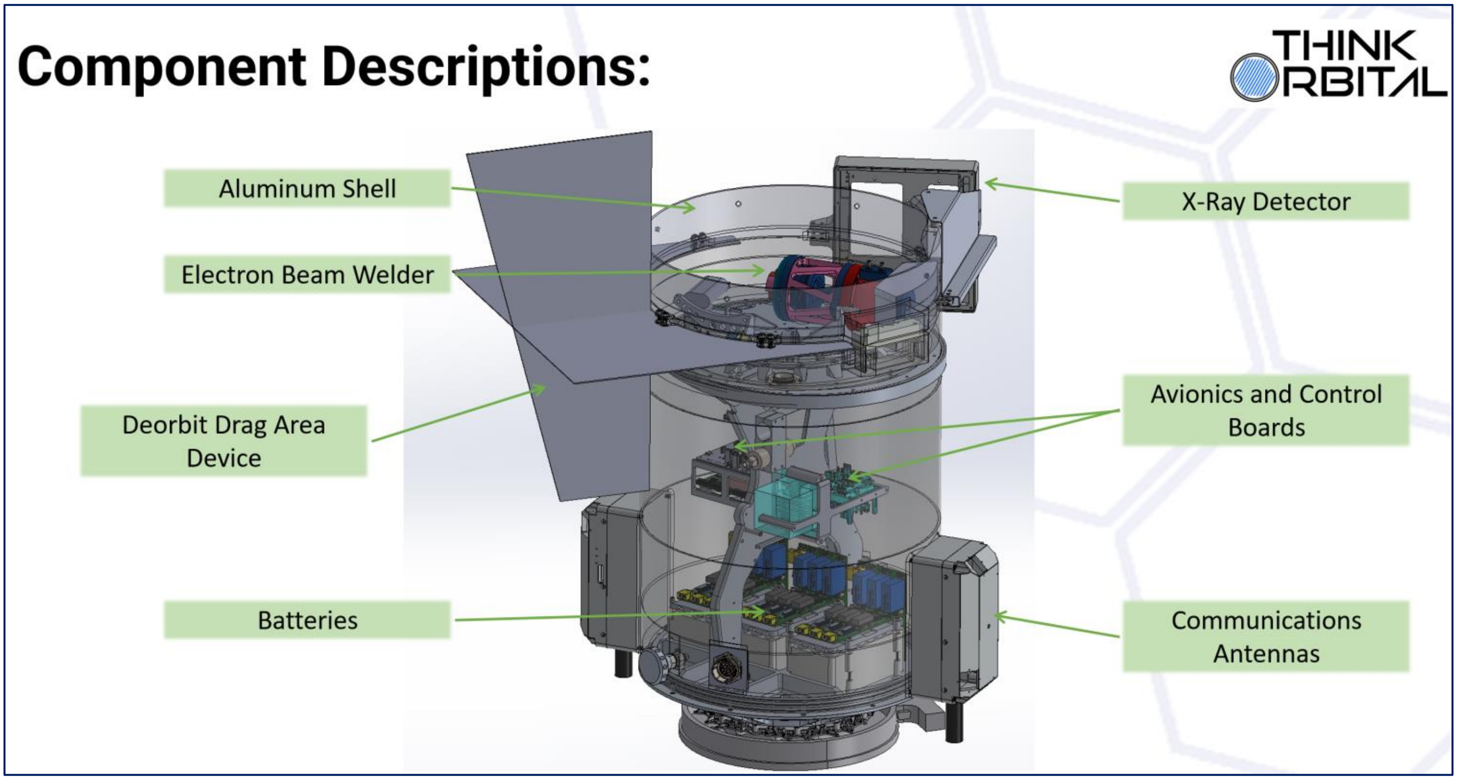




Introduction:

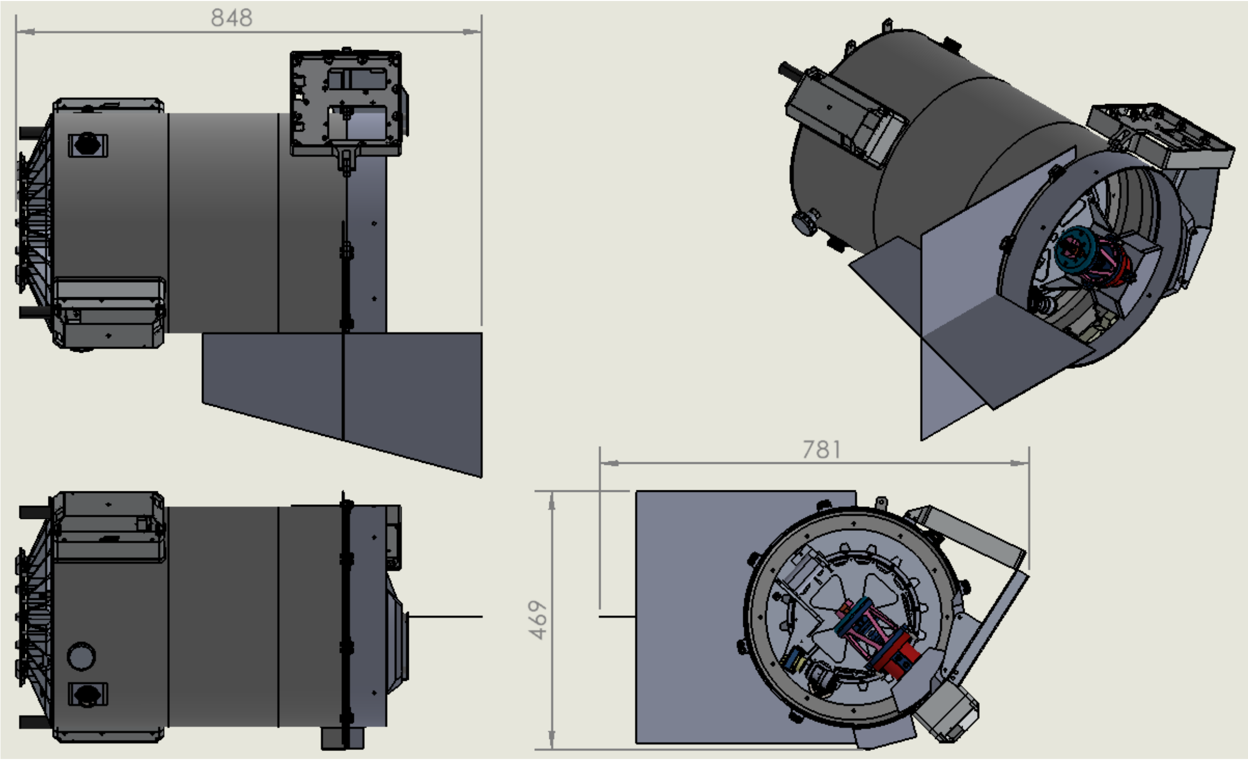
ThinkOrbital is launching a demonstration of in-space welding and inspection, planned on Bandwagon 2 with a launch date of approximately Dec 3, 2024. This payload contains an experimental electron beam welder and the batteries to support the experiment. The cylindrical payload is enclosed in a 6061 Aluminum Shell.

The 39.4 kg payload will be released into a 510km orbit at an inclination of approximately 45.4 Deg. A description of the significant componentry in the payload is shown below:



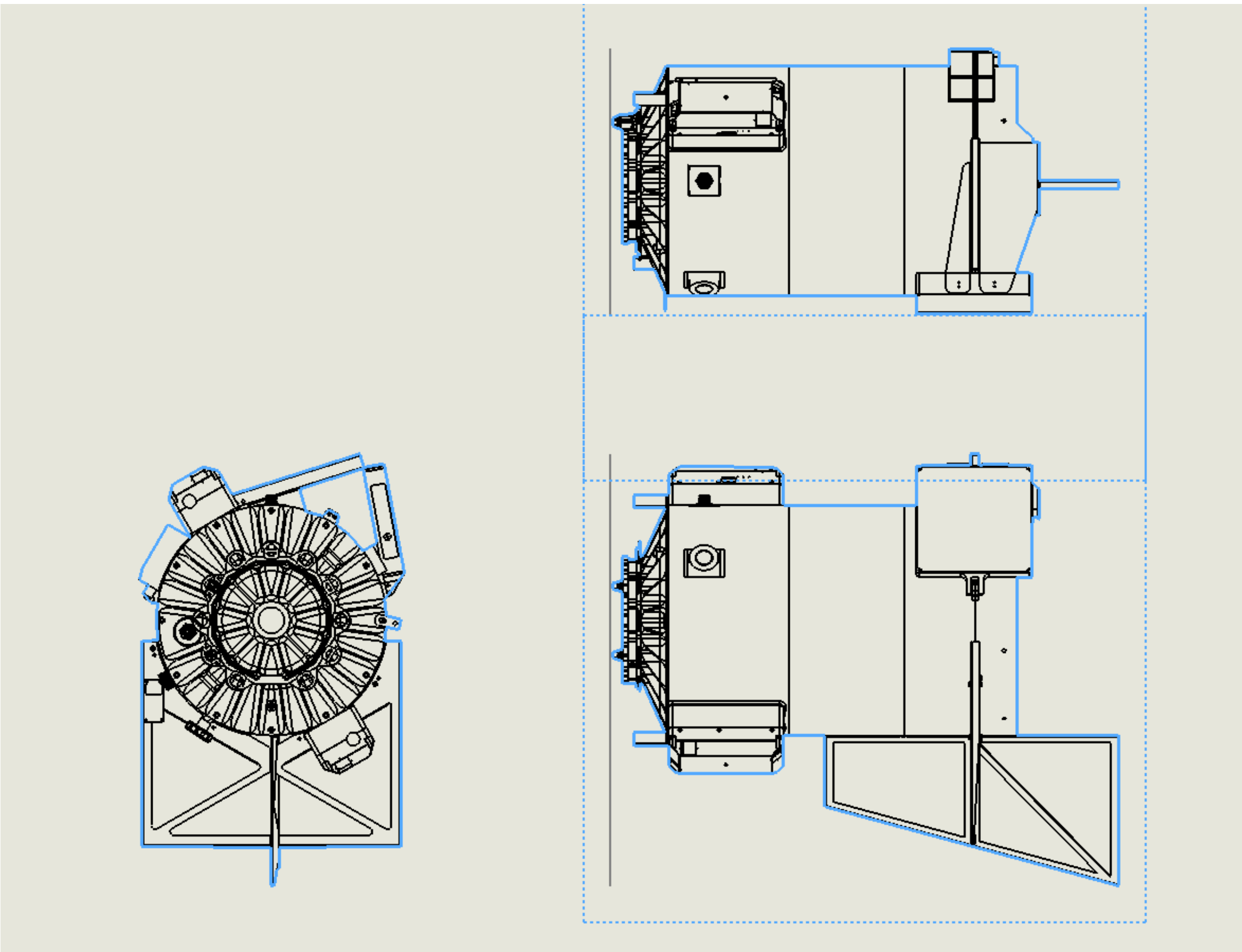
The payload will passively re-enter in less than 5 years, and complete demisability upon reentry is demonstrated via NASA DAS compliant with NASA-STD-8719.14C.

A detailed 3-view of the payload with dimensions (in mm) is shown below:

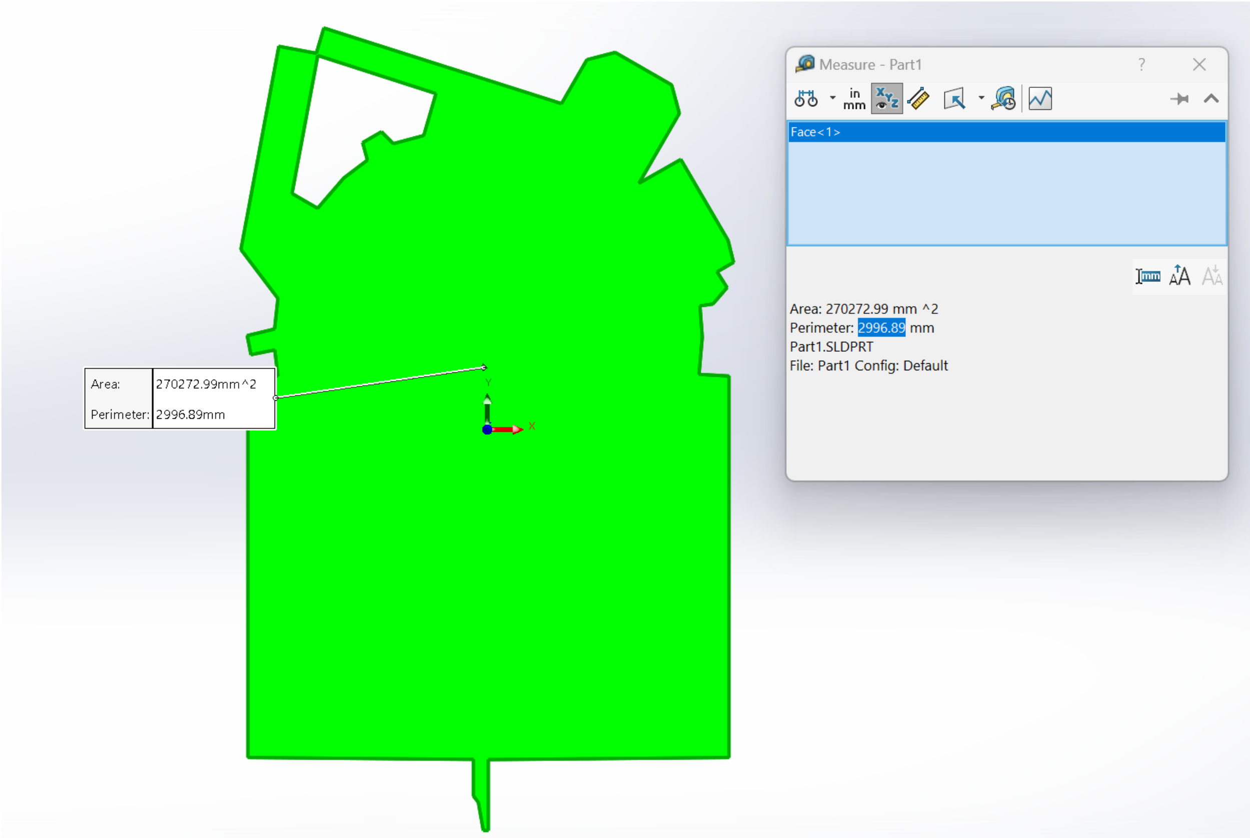


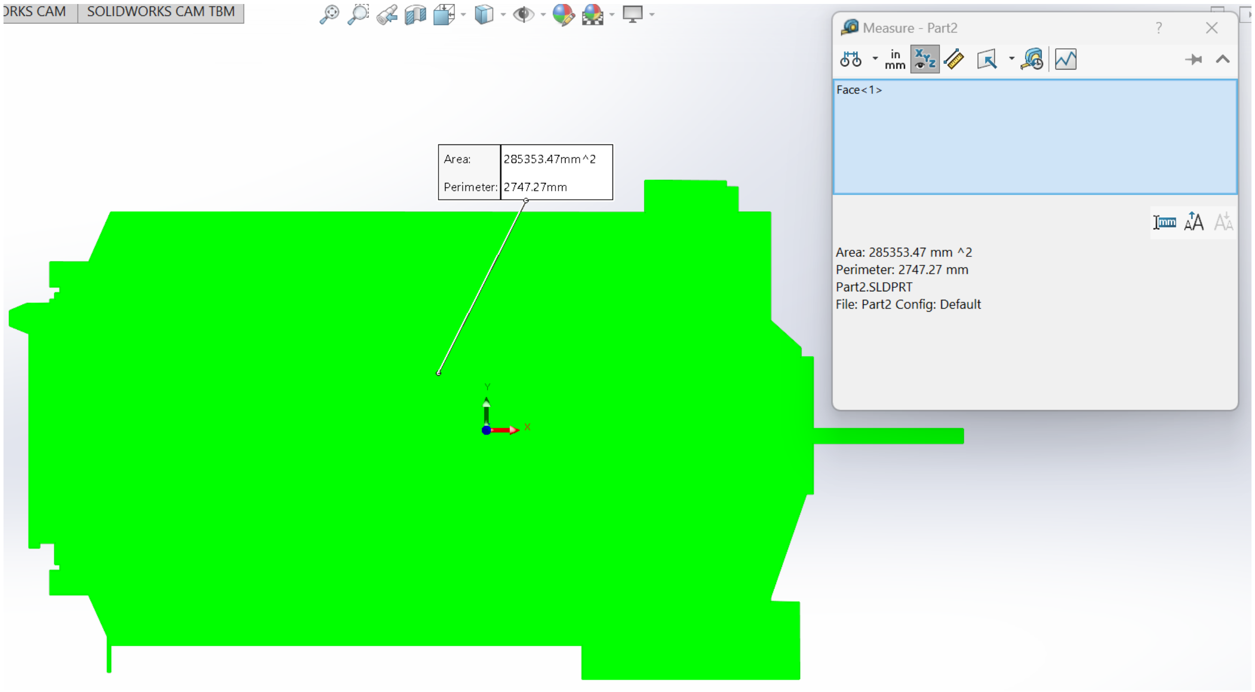
Equivalent Drag Area Figures and Calculations:

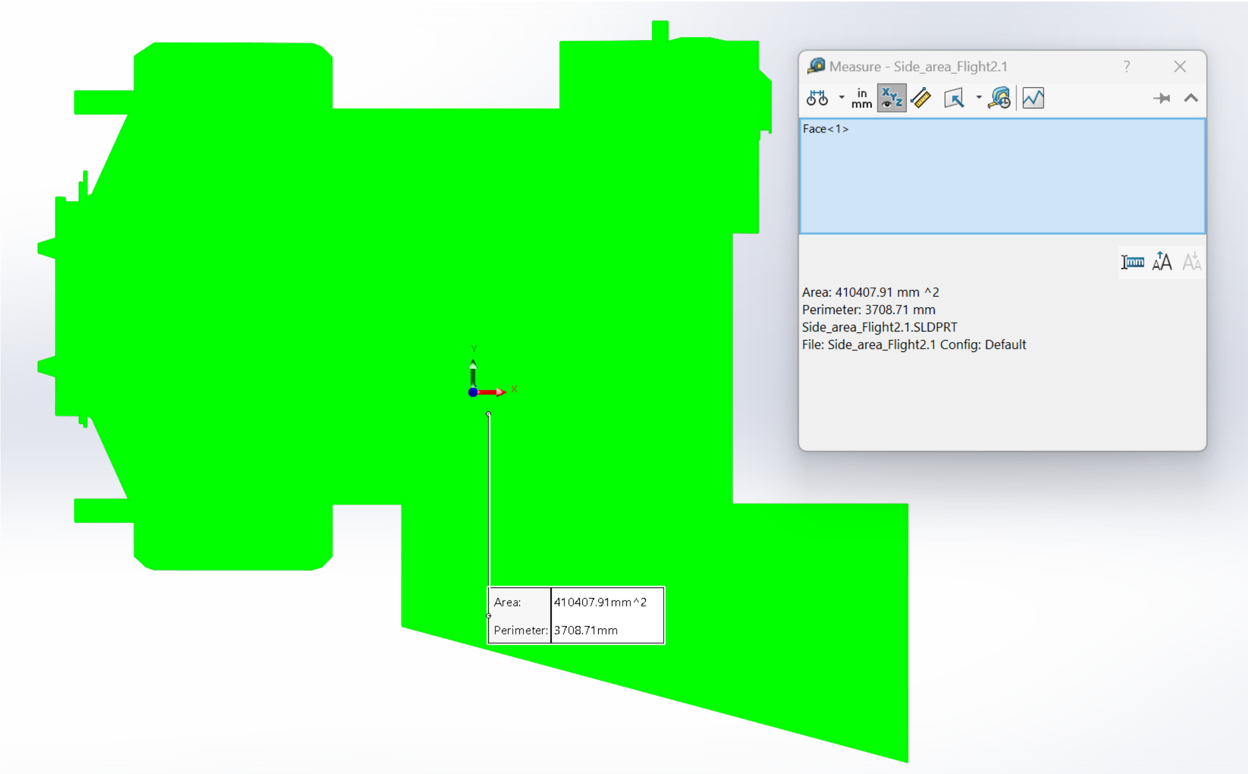
The equivalent drag area for TO Flight-2 was pulled from CAD for all 3-axis as shown below with silhouetted areas highlighted in blue.



The equivalent area of these plates' images are shown in the following 3-figures:


Area: 270272.99mm^2
Perimeter: 2996.89mm
Measure - Part1
Face<1>
Area: 270272.99 mm ^2
Perimeter: 2996.89 mm
Part1.SLDPRT
File: Part1 Config: Default


SOLIDWORKS CAM TBM
Area: 285353.47mm^2
Perimeter: 2747.27mm
Measure - Part2
Face<1>
Area: 285353.47 mm ^2
Perimeter: 2747.27 mm
Part2.SLDPRT
File: Part2 Config: Default



The areas were then combined into an equivalent random tumbling area per the equation of ISO 27852 as listed below and multiplied by a reduction factor of 80%(Per ISO 27852 low side error bound) to insure a conservative solution was reached.

In the absence of a more detailed model, a composite flat-plate model may be utilized. For example, for a plane sheet of which S is the area, it can be demonstrated that the "mean surface area" is S/2 when averaged over all possible viewing angles; by extension, for a parallelepiped-shaped spacecraft, S1, S2, S3 being the three surfaces (their opposite sides are to be neglected because when a side is visible, the opposite one is masked), it can be demonstrated that this "mean surface area" is (S1+S2+S3)/2; if a solar array of surface S4 is added, the mean surface area is then (S1+S2+S3+S4)/2 (neglecting any possible masking between the solar array and the spacecraft). This flat plate model has been shown to be accurate to within 20% for tracked

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ISO 27852:2010(E)

objects. Since masking effects represent a systematic bias that has the effect of reducing drag (thereby increasing orbit lifetime), an appropriately conservative cross-sectional area masking reduction factor shall be introduced to maintain accuracy.

To eliminate the need for such conservatism, this plate model approach can be extensively refined by integrating the cross-sectional area of the spacecraft across all anticipated tumbling attitudes (e.g. using a Computer-Aided Design or CAD program), and then dividing the result by the difference between the limits of integration. The analyst is then left with a properly weighted average cross-sectional area.

A summary of this calculation is shown below:

Current Areas (9/23/24):		
Top Down Area:	270000	mm^2
Side Area 1	410000	mm^2
Side Area 2	285000	mm^2
Composite Flat Plate Area:	482500	mm^2
Lower 80% Bound	386000	mm^2
Mass (Final as-built Weight):	39.4	kg
Area to Mass Ratio Current:	**0.0122**	**m^2/kg**
20 % Low Parameter used for DAS Analysis:	**0.0097**	**m^2/kg**

Requirement 4.3-1:

As analyzed via NASA DAS, the payload has a calculated object lifetime of 4.5 object-years, meeting the requirements of 4.3-1a of a lifetime less than 5 years and 4.3-2b of a total object-time product of less than 100 years for the mission.

Requirement 4.3-2:

As this payload is released at 510 km and maintains a LEO orbit with no sufficient energy to reach GEO or affect GEO debris, this payload meets this requirement.

Requirement 4.5-1:

As analyzed via NASA DAS, the payload has a probability of collision with a 10cm object of 1.6511e-6, or less than 0.001 as required and is in compliance with this requirement.

Requirement 4.5-2:

As analyzed via NASA DAS, the payload has a probably of penetration of 7.4923e-4, satisfying the requirement of a probability of collision less than 0.01 and as such, the payload is in compliance with this requirement.

Requirement 4.6-1 to 4.6-3:

Per section 4.3-1, the payload meets the requirements of 4.6, specifically:

1. The payload achieves natural reentry within 5 years of completion of mission.
2. Requirement 4.6-2 is N/A as the payload does not transit from LEO to GEO.
3. Requirement 4.6-3 is N/A as the payload does not transit from LEO to GEO.

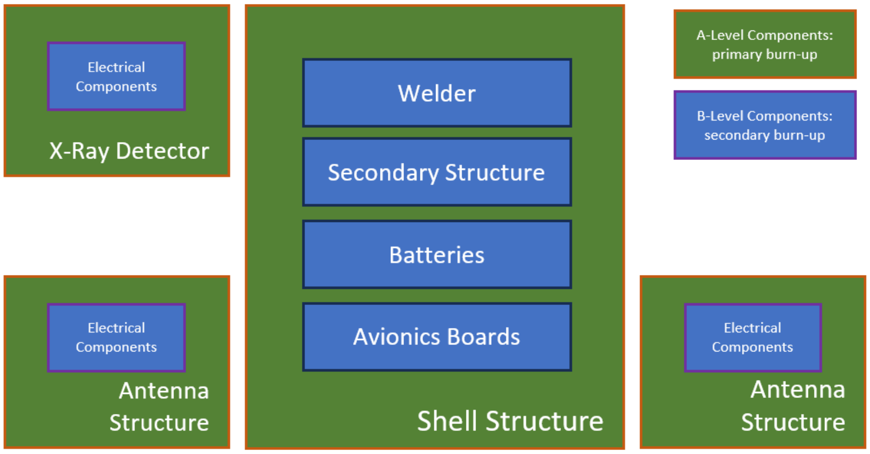
Requirement 4.7-1:

PER NASA DAS, the total risk of human casualty is below 1:10,000 or a 7m2 total debris casualty area, and as such is considered compliant per NASA-STD-8719.14C.

Analysis Method:

The payload is comprised of three primary constituents that represent initial components to be consumed in re-entry. After this, several secondary constituents are exposed and burnt up.

The block diagram of payload constituents are as follows:



Utilizing these components, via mass the payload is as follows:

ThinkOrbital Payload TO-2						
	QTY:	**Mass(kg):**	**Shape:**	**Material:**	**Length(mm):**	**Diameter(mm):**
1. Shell Primary Component	1	20	Cylinder	Aluminum	640	400
a. Internal Mechanical Structure:	1	5	Plate	Aluminum	450	250
b. TO Weld Head:	1			See Breakout	200	90
b.i. Upper Weld Head	1	0.8	Cylinder	Aluminum	40	90
b.ii. Weld Spacer	1	0.3	Cylinder	Alumina	80	90
b.iii. Welder interconnect Flange	1	0.4	Plate	Titanium	8	90
b.iv. Lower Welder	1	1.4	Cylinder	Aluminum	100	90
c. Batteries:	92	0.041	Cylinder	Lithium Polymer/Aluminum	65	19
d. avionics boards	6	0.1	Plate	Plastic/Lead/Copper	95	95
e. misc. bracketry	10	0.25	Plate	Aluminum	200	100
f. internal wiring	40	0.05	Cylinder	Copper	400	5
2. Antenna Primary Component	2	0.6	Rectangle	Aluminum	200	100
a. antenna control boards	2	0.28	Plate	Plastic/Lead/Copper	150	80
3. X-Ray Detector	1	2.7	Rectangle	Plastic	200	190
a. Internal electronics	1	0.6	Plate	Plastic/Lead/Copper	100	100

Utilizing these inputs, NASA DAS was run and the results indicated no survivable components(IE total demisability) well below the required 15 joules of energy, or a 1:10,000 risk of human casualty. The survivability output table is below, but the longest-survived component is the welding head, which is demised at 68 km altitude. The Comms antennas are demised at 77 km, and the shell is demised at 74 km.

Output

Object Name	Complia... Status	Risk of ... Casualty	SubCom... Object	Demise Altitude ...	Total De... Casualty...	Kinetic Energy (J)
			Shell Sys...	73.9	0.00	0.00
			Weld He...	68.0	0.00	0.00
			Batteries	73.8	0.00	0.00
			Avionics...	73.6	0.00	0.00
			Brackets	73.3	0.00	0.00

Messages

TO2 Requirement 4.7-1 Compliant
TO2Deorb Requirement 4.7-1 Compliant