Lightsail – 2

Orbital Debris Assessment Report
(ODAR)

Final
26 July 2017

Submitted by:

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Alex Diaz – Lightsail 2 Avionics Engineer

Record of Revisions

Revision	Date	Affected Pages	Description of Changes	Authors
Draft	23 Aug. 2016	All	Initial Document	Alex Diaz
Final	26 July 2017	3, 4, 5, 7, 11	Updates to mission summary	

Self- Assessment of the ODAR

A self-assessment of the ODAR is provided below.

Table 1: Orbital Debris Requirement Compliance Matrix

Requirement	Compliance Assessment	Comments
4.3-1a	Not applicable	No planned debris release
4.3-1b	Not applicable	No planned debris release
4.3-2	Not applicable	No planned debris release
4.4-1	Compliant	Minimal risk to orbital environment, mitigated by orbital lifetime.
4.4-2	Compliant	Minimal risk to orbital environment, mitigated by orbital lifetime.
4.4-3	Not applicable	No planned breakups
4.4-4	Not applicable	No planned breakups
4.5-1	Compliant	
4.5-2	Not applicable	
4.6-1(a)	Compliant	
4.6-1(b)	Not applicable	
4.6-1(c)	Not applicable	
4.6-2	Not applicable	
4.6-3	Not applicable	
4.6-4	Not applicable	Passive disposal
4.6-5	Compliant	
4.7-1	Compliant	Non-credible risk of human casualty
4.8-1	Compliant	No planned tether

Section 1: Program Management and Mission Overview

The Lightsail 2 mission, sponsored by The Planetary Society, will demonstrate controlled solar sailing in Earth orbit. Following spacecraft checkout, Lightsail-2 will deploy a 32 m^2 solar sail and will control the sail orientation relative to the sun direction, in order to shape the orbit.

LightSail 2: Bruce Betts, Program Manager; David Spencer, Project Manager

Launch vehicle and launch site: SpaceX Falcon Heavy from Cape Canaveral, FL.

Proposed launch date: Q2 2018

Mission duration: 6 weeks

Launch and deployment profile, including all parking, transfer, and operational orbits with apogee, perigee, and inclination:

The Lightsail-2 orbital elements are defined as follows:

Apogee: 720 km
Perigee: 720 km
Inclination: 24.0 degrees

Foreign government or space agency participation:

- No foreign agency is participating in this mission. All personnel are United States citizens.

Summary of NASA's responsibility under the governing agreement(s):

- Not applicable.

Table 2: Program Milestone Schedule

Program Milestone Schedule	
Task	Date
CubeSat Build, Test, and Integration	Q1-2015 Q3 2016
Flight Unit Integration and Testing	Q1-Q3 2016
Environmental Testing	Q4 2016
Mission Readiness Review	Q1 2017
P-POD Integration and Shipment	Q2-Q3 2017
Launch	Q2 2018
Deployment and Operations	Q3-Q4 2017

Section 2: Spacecraft Description

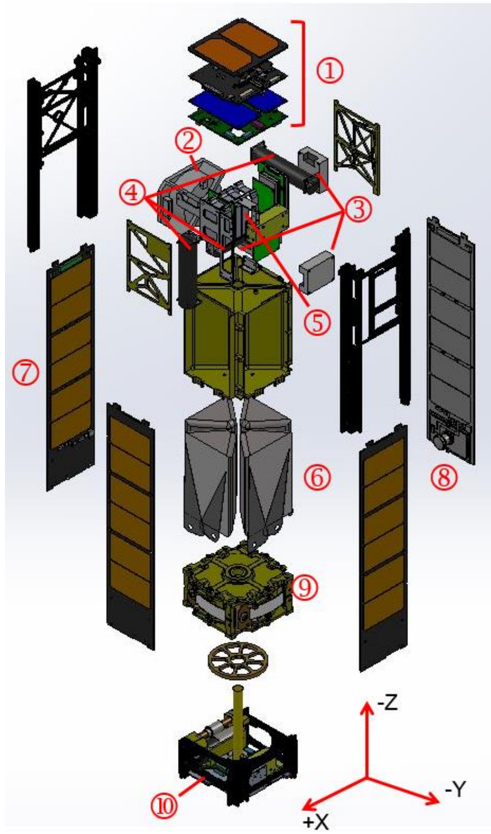
Physical Description of the spacecraft:

LightSail 2 is a 3U CubeSat (10 cm x 10cm x 34 cm), with mass of 4.85 kg total.

Table 3: Lightsail -B Summary

CubeSat Quantity	CubeSat size	CubeSat Name	CubeSat Mass (kg)
1	3U (10cm X 10cm X 34cm)	LightSail 2	4.85

LightSail 2 – The Planetary Society – 3U CubeSat



No.	Subsystem
1	Avionics
2	Momentum Wheel Mass Model
3	Gyros
4	Torque Rods
5	Battery Module
6	Stowed Solar Sail
7	Solar Panel
8	Camera
9	Sail Deployer
10	Antenna

Figure 1: LightSail-A Expanded View

LightSail 2 shown in Figure 1, is the second privately developed solar sail project conceived and led by The Planetary Society. It will deploy of a ~32 m^2 Mylar sail and demonstrate solar sailing by raising its orbit apogee. Partners include Ecliptic Enterprises Corporation, the Georgia Institute of Technology, Boreal Space, and Cal Poly SLO.

LightSail 2 will launch within a P-POD that is embedded within the Prox-1 small satellite. Upon ejection from the P-POD, LightSail 2 will begin the boot-up sequence. After successful completion of boot-up sequence, the unit will start up the ACS and go into detumble mode. At 45 minutes after ejection, the antenna will deploy and UHF beacon will commence shortly after. The ground team will acquire and track LightSail 2 for approximately 2 weeks, verifying all parameters are within tolerance. After 2 weeks, the solar panels and solar sail will deploy. Orbit raising operations will then begin for a period of 4 weeks. During this time LS2 will downlink image, and track orbital change. LightSail 2 will deorbit several weeks after.

The CubeSat structure is made of Aluminum 6061-T6. It contains all standard commercial off the shelf (COTS) materials, electrical components, PCBs and solar cells. The payload consists of a 32 m^2 Mylar solar sail with a custom metal boom.

There are no pressure vessels, hazardous or exotic materials.

The electrical power storage system consists of common lithium-polymer batteries with over-charge/current protection circuitry. The batteries are not UL listed, however the batteries will be tested per AFSPCMAN 91-710 to ensure compliance with safety requirements.

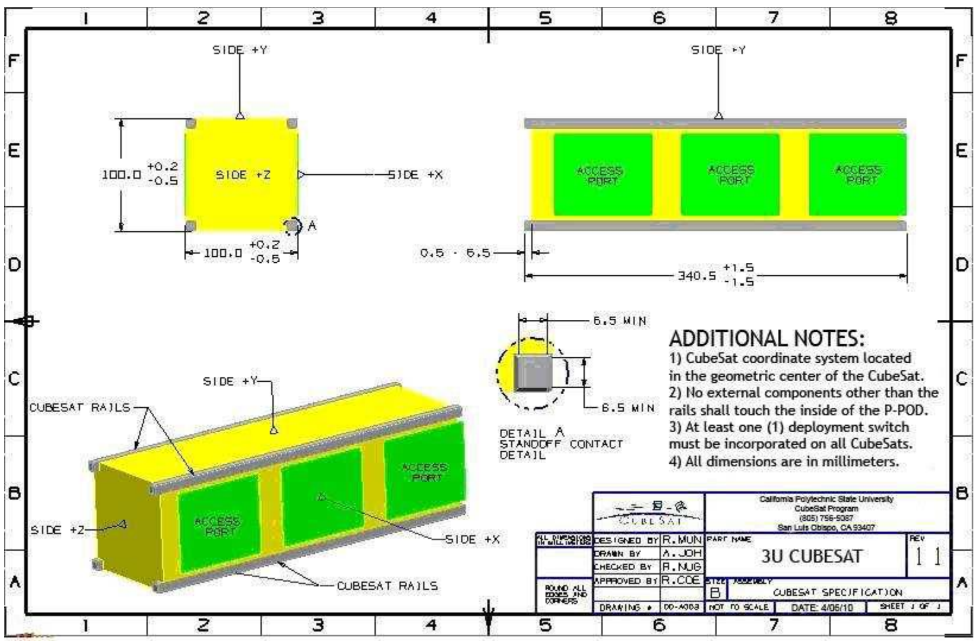


Figure 2: 3U CubeSat Specification

Section 3: Assessment of Spacecraft Debris Released during Normal Operations

No releases are planned on the Lightsail-2 CubeSat mission therefore this section is not applicable.

The assessment of spacecraft debris requires the identification of any object (>1 mm) expected to be released from the spacecraft any time after launch, including object dimensions, mass, and material.

Section 3 requires rationale/necessity for release of each object, time of release of each object, relative to launch time, release velocity of each object with respect to spacecraft, expected orbital parameters (apogee, perigee, and inclination) of each object after release, calculated orbital lifetime of each object, including time spent in Low Earth Orbit (LEO), and an assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2.

Section 4: Assessment of Spacecraft Intentional Breakups and Potential for Explosions.

There are NO plans for designed spacecraft breakups, explosions, or intentional collisions on the Lightsail-2 mission. No passivation of components is planned at the End of Mission for the LightSail-2 CubeSat.

The probability of battery explosion is very low, and, due to the very small mass of the satellites and their short orbital lifetimes the effect of an explosion on the far-term LEO environment is negligible (ref (i)).

The CubeSats batteries still meet Req. 56450 (4.4-2) by virtue of the HQ OSMA policy regarding CubeSat battery disconnect stating;

> "CubeSats as a satellite class need not disconnect their batteries if flown in LEO with orbital lifetimes less than 25 years." (ref. (i))

Section 5: Assessment of Spacecraft Potential for On-Orbit Collisions

Calculation of spacecraft probability of collision with space objects larger than 10 cm in diameter during the orbital lifetime of the spacecraft takes into account both the mean cross sectional area and orbital lifetime.

The largest mean cross sectional area (CSA) of LightSail 2 is when it is fully deployed with antennas and solar sail deployed (10cm x 10cm x 34cm with four deployable solar panels 7.8cm x 32 cm and a deployable solar sail 557cm x 557cm):

$$\boldsymbol{Mean\ CSA} = \frac{\sum \boldsymbol{Surface\ Area}}{\boldsymbol{4}} = \frac{[\boldsymbol{2} * (\boldsymbol{w} * \boldsymbol{l}) + \boldsymbol{4} * (\boldsymbol{w} * \boldsymbol{h})]}{\boldsymbol{4}}$$

Equation 1: Mean Cross Sectional Area for Convex Objects

The LightSail 2 CubeSat evaluated for this ODAR is stowed in a convex configuration, indicating there are no elements of the CubeSats obscuring another element of the same CubeSats from view. Thus, mean CSA for all stowed CubeSats was calculated using Equation 1. This configuration renders the longest orbital lifetimes.

LightSail 2 will be in the stowed configuration immediately after being ejected from the P-POD. After two weeks the solar panels will be commanded to deploy and detumble operations begin. While the CubeSat is tumbling Equation 1 is valid. Once attitude control has been established cross sectional area is now determined by what surface area is exposed normal to the velocity vector.

Following solar sail deployment, LightSail 2 will follow an attitude profile that places the solar sail edge-on to the Sun direction for half of the orbit, and face-on to the Sun for half the orbit.

In determining the cross sectional area used in the DAS (Debris Assessment Software) analysis various orientations and configurations were considered. While stowed and tumbling the average cross sectional area is approximated ¼ the total surface area (ref (b)). During the operation mode the largest cross sectional area exposed to the velocity vector results when the 15 degree offset causes the solar sail to have an effective height of 144 cm and width of 557 cm. In the worst case orbit lifetime scenario the full solar sail is presented to the velocity vector. In both operational and worst case modes the solar sail obscures the additional CubeSat geometry.

The LightSail 2 orbit at deployment is 720 km apogee altitude by 720 km perigee altitude, with an inclination of 24 degrees. With an area to mass (4.85 kg) ratio of 0.0081 m^2/kg. In the stowed configuration, DAS yields 91.2 years for orbit lifetime, which in turn is used to obtain the collision probability. With the sail stowed, LightSail 2 will see a probability of collision with large objects of 2.5×10^{-5} and with the sail deployed LightSail 2 sees a probability of collision of 7.9×10^{-5}. Table 4 below provides complete results.

Table 4: CubeSat Orbital Lifetime & Collision Probability

	Configuration	Stowed[1]	Deployed[2]	Worst Case[3]
	Mass (kg)	4.85	4.85	4.85
LightSail-2	**C/S Area (m^2)**	0.039[4]	8.0	31.0
	Area-to Mass (m^2/kg)	0.008	1.7	6.4
	Orbital Lifetime	91.2 yrs	3.28 yrs	.98 yrs
	Probability of collision	2.5x10^-5	7.9x10^-5	1x10^-4

1. Stowed configuration is in a tumble as deployed from P-POD without any deployed components.
2. Operational attitude indicates fully deployed solar sail and solar panels with ACS stabilized +/- 15 degree of Z-axis from nadir. The solar sail is assumed to be edge-on to the velocity vector +/- 15 degrees.
3. Worst Case configuration presents the solar sail normal to the velocity vector.
4. Mean cross sectional area.

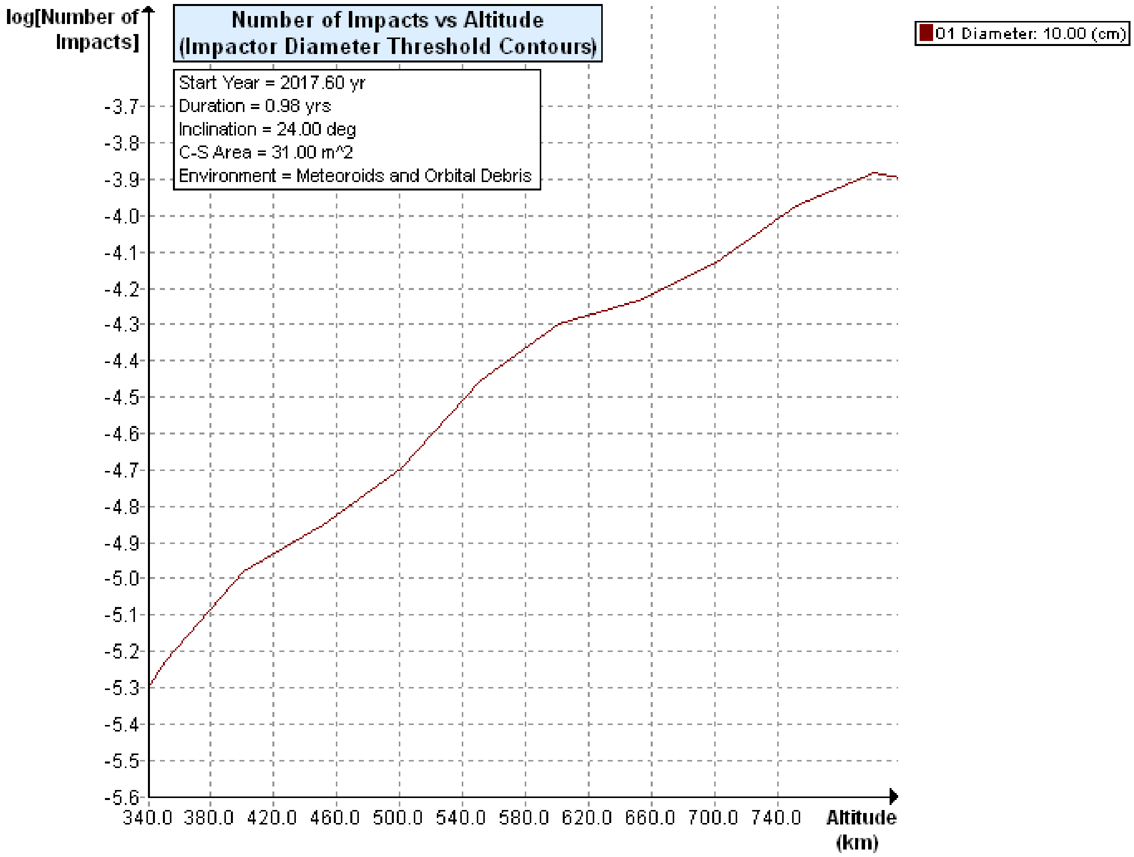


Figure 3: Risk of Orbit Collision vs. Altitude (LightSail 2)

There will be no post-mission disposal operation. As such the identification of all systems and components required to accomplish post-mission disposal operation, including passivation and maneuvering, is not applicable.

The probability of a LightSail 2 collision with debris and meteoroids greater than 10 cm in diameter was calculated with DAS to be 1x10^-4 in a worst case situation. This satisfies the 0.001 maximum probability requirement 4.5-1.

Since the CubeSats have no capability or plan for end-of-mission disposal, requirement 4.5-2 is not applicable.

Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

LightSail 2 will naturally decay from orbit within 25 years after end of the mission, satisfying requirement 4.6-1a detailing the spacecraft disposal option.

Planning for spacecraft maneuvers to accomplish postmission disposal is not applicable. Disposal is achieved via passive atmospheric reentry.

Calculating the area-to-mass ratio for the worst-case (smallest Area-to-Mass) post-mission disposal among the CubeSats finds LightSail 2 in its stowed configuration as the worst case. The area-to-mass is calculated for is as follows:

$$\frac{\boldsymbol{Mean}\ {}^{\boldsymbol{C}}\!/_{\boldsymbol{S}}\ \boldsymbol{Area}\ (\boldsymbol{m^2})}{\boldsymbol{Mass}\ (\boldsymbol{kg})} = \boldsymbol{Area-to-Mass}\ (\frac{\boldsymbol{m^2}}{\boldsymbol{kg}})$$

Equation 2: Area to Mass

$$\frac{0.0391\ m^2}{4.85\ kg} = 0.0081\,\frac{m^2}{kg}$$

A stowed LightSail 2 has the smallest Area-to-Mass ratio and as a result will have the longest orbital lifetime. The assessment of the spacecraft illustrates it is compliant with Requirements 4.6-1 through 4.6-5.

<u>DAS 2.0.2 Orbital Lifetime Calculations:</u>

DAS inputs are: 720 km maximum perigee 720 km maximum apogee altitudes with an inclination of 24 degrees at deployment in the year 2017.6. An area to mass ratio of 0.0081 m^2/kg for the LightSail 2 CubeSat was inputed. DAS 2.0.2 yields a 91.2 year orbit lifetime for LightSail 2 in its stowed state.

This meets requirement 4.6-1. For the complete list of CubeSat orbital lifetimes reference.

Assessment results show compliance.

Section 7: Assessment of Spacecraft Reentry Hazards

A detailed assessment of the components to be flown on Lightsail-2 was performed. The assessment used DAS 2.0, a conservative tool used by the NASA Orbital Debris Office to verify Requirement 4.7-1. The analysis is intended to provide a bounding analysis for characterizing the survivability of a CubeSat's component during re-entry. For example, when DAS shows a component surviving reentry it is not considering the material ablating away or charring due to oxidative heating. Both physical effects are experienced upon reentry and will decrease the mass and size of the real-life components as the reenter the atmosphere, reducing the risk they pose still further.

The following steps are used to identify and evaluate a component's potential reentry risk relative to the 4.7-1 requirement of having less than 15 J of kinetic energy and a 1:10,000 probability of a human casualty in the event the survive reentry.

1. Low melting temperature (less than 1000 °C) components are identified as materials that would never survive reentry and pose no risk to human casualty. This is confirmed through DAS analysis that showed materials with melting temperatures equal to or below that of copper (1080 °C) will always demise upon reentry for any size component up to the dimensions of a 1U CubeSat.

2. The remaining high temperature materials are shown to pose negligible risk to human casualty through a bounding DAS analysis of the highest temperature components, stainless steel (1500°C). If a component is of similar dimensions and has a melting temperature between 1000 °C and 1500°C, it can be expected to posses the same negligible risk as stainless steel components. See Table 5.

Table 5: Lightsail-2 Stainless Steel DAS Analysis

Lightsail-2 Stainless Steel Components	Mass (g)	Diameter/ Width (cm)	Length (cm)	Height (cm)		Demise Alt (km)	KE (J)
Antenna	2.3	0.6	17.3	0.025		0	0
Panel Hinge Shaft	3	0.24	4.8	-		77.3	0
Deployable Panel Spring	0.4	0.5	0.56	-		77.1	0
Battery Mount Shaft	1.7	0.24	5.6	-		62.9	0
Board Stack Standoff	1.1	0.6	0.6	-		72	0
#2-56 SHBS 1"	0.6	0.22	2.5	-		69.4	0
#4-40 x 3/8" SHCS	0.5	0.28	0.95	-		72.1	0
0.0012	1.2	0.28	0.3	-		67.5	0
#2-56 SHBS 3/4"	0.5	0.22	1.9	-		70.4	0
#2-56 SHBS 1"	0.5	0.22	2.5	-		70.4	0
#2-56 SHBS 3/16"	0.2	0.22	0.48	-		74	0
#0-80 x 0.125" SHCS	0.1	0.15	0.3	-		74.1	0

The majority of stainless steel components demise upon reentry. The component that DAS conservatively identifies as reaching the ground have 0 joules of kinetic energy, far below the requirement of 15 joules. No stainless steel component will pose a risk to human casualty as defined by the Range Commander's Council. In fact, any injury incurred or inflicted by an object with such low energy would be negligible and wouldn't require the individual to seek medical attention.

Through the method described above, Table 5: Lightsail-2 Stainless Steel DAS Analysis, Lightsail 2 has been conservatively shown to be in compliance with Requirement 4.7-1 of NASA-STD-8719.14A.

See the Appendix for a complete accounting of the survivability of all CubeSat components.

Section 8: Assessment for Tether Missions

Lightsail-2 will not be deploying any tethers.

Lightsail-2 satisfy Section 8's requirement 4.8-1.

Appendix Index:

Appendix A. Lightsail -2 Component List

Name	External/Internal (Major/Minor Components)	Qty	Material	Body Type	Mass (g)	Diameter/ Width (mm)	Length (mm)	Height (mm)	Low Melting	Melting Temp (°C)	Comment
LightSail 2		1		3U CubeSat							
CubeSat Structure: Main Side	External - Major	2	Aluminum 6061-T6	Box	142	100	340.5	17	yes	284	Demise
CubeSat Structure: Plate	External - Major	2	Aluminum 6061-T6	Plate	28	8	9.5	0.3	yes	-	Demises
Antenna	External - Major	1	Blue Clock Spring Steel (SAE 1095;ASTM A684)	Strip	2.3	6	173	0.25	no	1650	Negligible Risk: KE ~ 0 J. See Table 5
Solar Panels	External - Major	4	FR4	Rectangular	172	78	320	1.5	yes	-	Demise
Solar Sail	External - Major	4	Aluminized Mylar	Triangle	126	5570	2x 3930		yes	-	Demise
Solar Sail TRAC Boom: AFRL	External - Major	4	Elgiloy (40% Co; 20% Cr; 15% Ni alloy) 85% Cold Reduction	2 strips	227	20	4000	20	yes	-	Demise
Camera: Aerospace Corp.	External - Major	2	Aluminum housing 6061-T6	Rectangular	30.2	69	44	30	yes	-	Demise
Sep Switches	External - Minor	2	PPS/PBT Polymer Housing	Box		2.7	10.5	8.2	yes	-	Demise
Sun Sensor	External - Minor	2	FR4	Board	2.2	7	23	1.6	yes	-	Demise
Panel Hinge Shaft	External - Minor	4	316 Stainless Steel	Rod	3	2.4	48		no	1399	Demise; see Table 5
Hinge Plate Left	External - Minor	8	Aluminum 6061-T6	Plate	1	10	8	5.6	yes	-	Demise
Hinge Plate Right	External - Minor	8	Aluminum 6061-T6	Plate	1	10	8	5.6	yes	-	Demise
Deployable Panel Bushing	External - Minor	8	Delrin AF	Bushing	0.04	4	1.4		yes	-	Demise
Deployable Panel Stop	External - Minor	4	Aluminum 6061-T6	Triangle	1.8	25	25	4	yes	-	Demise
Deployable Panel Spring	External - Minor	8	302 Stainless Steel	Spring	0.4	5	5.6		no	1538	Demise; see Table 5
Solar Cells: Spectro Lab	External - Minor	52	Germanium	Flat panel	3.8	69	40	0.2	yes	-	Demise

Name	External/Internal (Major/Minor Components)	Qty	Material	Body Type	Mass (g)	Diameter/ Width (mm)	Length (mm)	Height (mm)	Low Melting	Melting Temp (°C)	Comment
Batteries	Internal - Major	8 cells	Lithium Polymer	Rectangular	15	49	30	6	yes	-	Demise
Torque Rod	Internal - Major	3	Al housing/Cu coils/Adhesive	Rod	170	22	94		yes	-	Demise
Payload Board: Stellar	Internal - Major	1	FR4	Board	39.6	83	83	5	yes	-	Demise
Motherboard Assembly (includes transiever): Tyvak	Internal - Major	1	FR4	Board	75.6	83	83	5	yes	-	Demise
Battery Board: Cal Poly	Internal - Major	1	FR4	Board	12.2	43	50	4	yes	-	Demise
Sail Housing	Internal - Major	1	Aluminum 6061-T6	Box	238	100	100	122.5	yes	-	Demise
Boom Housing	Internal - Major	1	Aluminum 6061-T6	Box	387	103	103	46	yes	-	Demise
Gyro: Analog Devices	Internal - Minor	3	component	Box	25	36	44	14	yes	-	Demise
Battery Retainer	Internal - Minor	4	Delrin	Box	4	33	60	10	yes	-	Demise
Battery Mount Shaft	Internal - Minor	3	18-8 Stainless Steel	Rod	1.7	2.4	56		no	1450	Demise; see Table 5
Torque Rod Mounts	Internal - Minor	6	Aluminum 6061-T6	Plate	3.2	22	13	2	yes	-	Demise
Momemtum Wheel Mass Model	Internal - Minor	1	6061-T6	Circular Box	230.6	75	68	35	yes	-	Demise
Board Stack Standoff	Internal - Minor	4	18-8 Stainless Steel	Ring	1.1	6	6	-	no	1450	Demise; see Table 5
Corner Cube	Internal - Minor	4	N-BK7 Glass	Cube	1.7	10	10	10	yes	-	Demise
#2-56 SHBS 1"	Internal - Minor	4	18-8 Stainless Steel	screw	0.6	2.2	25	-	no	1450	Demise; see Table 5
#4-40 x 3/8" SHCS	Internal - Minor	12	316 Stainless Steel	screw	0.5	2.8	9.5	-	no	1399	Demise; see Table 5
#4-40 Shoulder Screw	Internal - Minor	8	18-8 Stainless Steel	screw	1.2	2.8	3	-	no	1450	Demise; see Table 5
#2-56 SHBS 3/4"	Internal - Minor	4	18-8 Stainless Steel	screw	0.5	2.2	19	-	no	1450	Demise; see Table 5
#2-56 SHBS 1"	Internal - Minor	8	18-8 Stainless Steel	screw	0.5	2.2	25	-	no	1450	Demise; see Table 5
#2-56 SHBS 3/16"	Internal - Minor	34	18-8 Stainless Steel	screw	0.2	2.2	4.8	-	no	1450	Demise; see Table 5

Name	External/Internal (Major/Minor Components)	Qty	Material	Body Type	Mass (g)	Diameter/ Width (mm)	Length (mm)	Height (mm)	Low Melting	Melting Temp (°C)	Comment
Main Harness with connectors	Internal - Minor	1	Copper Wire/Polyamide/Black LCP Insulation	wire	22	-	-	-	yes	-	Demise
Panel Harness	Internal - Minor	2	Copper/Kapton	wire	0.6	-	-	-	yes	-	Demise
Flex Cables	Internal - Minor	4	Kapton/Copper	flat wire	0.2	-	-	-	yes	-	Demise
RF Cable	Internal - Minor	1	Phosphor Bronze/Silver/Brass	wire	1.7	-	-	-	yes	-	Demise