ELVL-2018-0045482 Rev B
June 25, 2019

Orbital Debris Assessment for the EdgeCube Mission per NASA-STD 8719.14B

Signature Page

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ELVL-2018-0045482 Rev B

Reply to Attn of: VA-H1

June 25, 2019

TO: Scott Higginbotham, LSP Mission Manager, NASA/KSC/VA-C

FROM: Yusef Johnson, a.i. solutions/KSC/AIS2

SUBJECT: Orbital Debris Assessment Report (ODAR) for the EdgeCube CubeSat

REFERENCES:

A. *NASA Procedural Requirements for Limiting Orbital Debris Generation*, NPR 8715.6B, 6 February 2017
B. *Process for Limiting Orbital Debris*, NASA-STD-8719.14B, 25 April 2019
C. International Space Station Reference Trajectory, delivered May 2019
D. McKissock, Barbara, Patricia Loyselle, and Elisa Vogel. *Guidelines on Lithium-ion Battery Use in Space Applications*. Tech. no. RP-08-75. NASA Glenn Research Center Cleveland, Ohio
E. *UL Standard for Safety for Lithium Batteries, UL 1642*. UL Standard. 5th ed. Northbrook, IL, Underwriters Laboratories, 2012
F. Kwas, Robert. Thermal Analysis of ELaNa-4 CubeSat Batteries, ELVL-2012-0043254; Nov 2012
G. Range Safety User Requirements Manual Volume 3- Launch Vehicles, Payloads, and Ground Support Systems Requirements, AFSCM 91-710 V3.
H. HQ OSMA Policy Memo/Email to 8719.14: CubeSat Battery Non-Passivation, Suzanne Aleman to Justin Treptow, 10, March 2014

The intent of this report is to satisfy the orbital debris requirements listed in ref. (a) for the EdgeCube CubeSat, which will be deployed from the Commercial Resupply Services (CRS) NG-12 Cygnus spacecraft, post-ISS departure. It serves as the final submittal in support of the spacecraft Safety and Mission Success Review (SMSR). Sections 1 through 8 of ref. (b) are addressed in this document; sections 9 through 14 fall under the requirements levied on the primary mission and are not presented here. This CubeSat will passively reenter, and therefore this ODAR will also serve as the End of Mission Plan (EOMP) for this CubeSat.

RECORD OF REVISIONS		
REV	**DESCRIPTION**	**DATE**
0	Original submission	December 2018
A	Updated mass properties	April 2019
B	Corrected typographical errors, updated reference document, added EOMP language	June 2019

The following table summarizes the compliance status of the EdgeCube CubeSat to be deployed from the Cygnus spacecraft. EdgeCube is fully compliant with all applicable requirements.

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	On board energy source (batteries) incapable of debris-producing failure
4.4-2	Compliant	On board energy source (batteries) incapable of debris-producing failure
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	Worst case lifetime 2.98 yrs
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 release for EdgeCube

Section 1: Program Management and Mission Overview

EdgeCube is sponsored by the Human Exploration and Operations Mission Directorate at NASA Headquarters. The Program Executive is John Guidi. Responsible program/project manager and senior scientific and management personnel are as follows:

EdgeCube: PI: Dr. Lynn Cominski, Sonoma State University; PM: Garrett Jernigan, H-Bar Research

Program Milestone Schedule	
Task	**Date**
CubeSat Selection	February 2017
Delivery to Spaceflight/SEOPS	August 2019
Launch	4 December 2019
Deployment	NET January 2020

Figure 1: Program Milestone Schedule

EdgeCube will be launched as a payload on the Falcon 9 launch vehicle executing the SPX-19 mission. EdgeCube will then be installed upon and deployed from the NG-12 Cygnus spacecraft post-ISS undocking. EdgeCube's attributes are identified in Table 2: .

Section 2: Spacecraft Description

Table 2: outlines the generic attributes of the spacecraft.

Table 2: EdgeCube Attributes

CubeSat Names	CubeSat Quantity	CubeSat size (mm^3)	CubeSat Masses (kg)
EdgeCube	1	100 x 100 x 100	1.48

The following pages describe the EdgeCube CubeSat.

EdgeCube– Sonoma State University – 1U

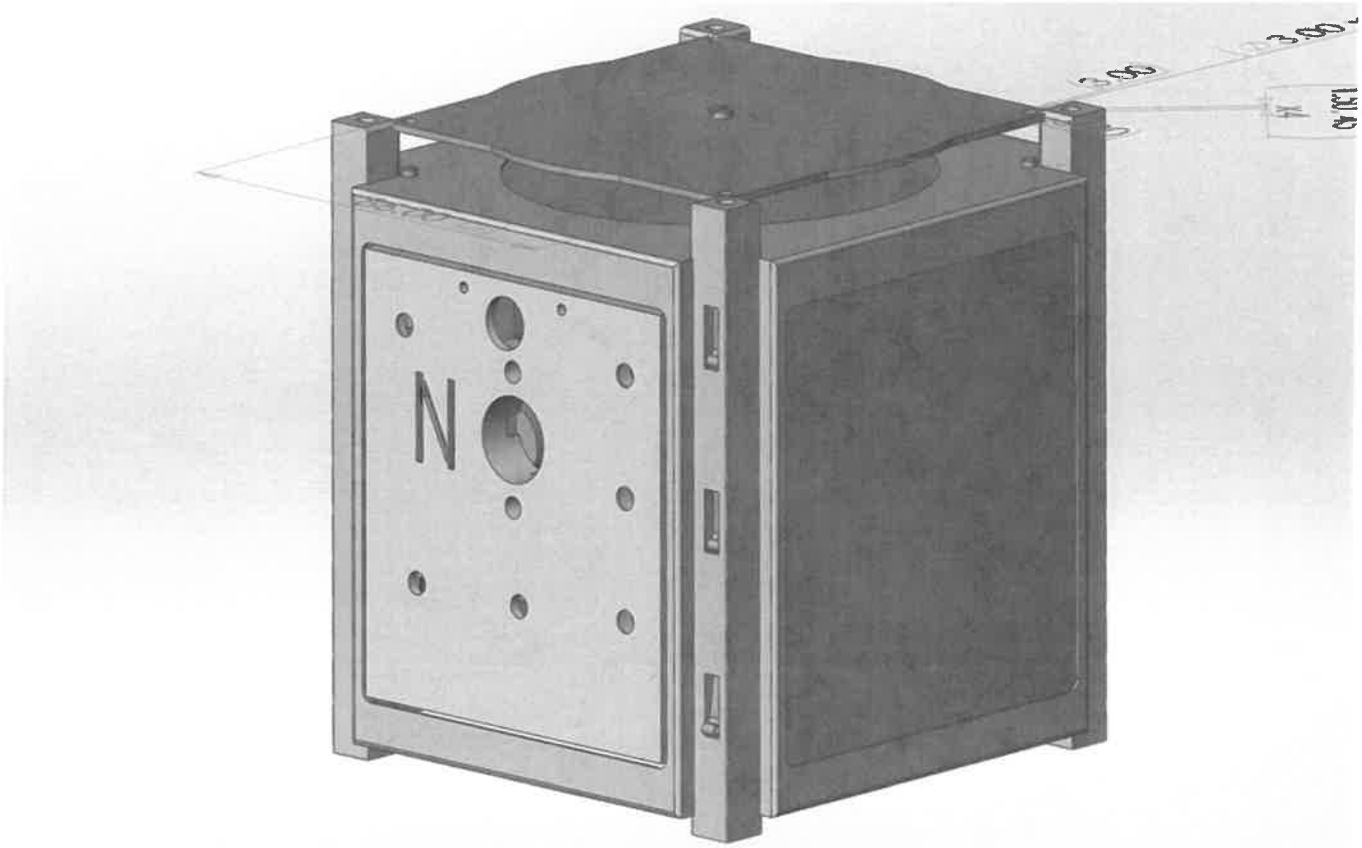

Figure 2: EdgeCube assembled view (with fixed antenna formed by the top PC board)

Overview

EdgeCube will make a global measurement of the red edge that monitors a sharp change in leaf reflectance due to changes in vegetation chlorophyll absorption and mesophyll scattering due to seasonal leaf phenology or stress. EdgeCube has been specifically designed to monitor the red edge characteristics of approximately 200 km areas of the Earth, using 9 narrow spectral bands on the 600-800 nm wavelength range. Although EdgeCube's ground spatial resolution is substantially less conventional multispectral satellites, its design will monitor changes in the red-edge on a global scale within the telemetry limitations of a CubeSat.

CONOPS

EdgeCube is mounted in the launch dispenser with a fixed antenna on the top of the spacecraft. This antenna is formed by a PC board that is entirely within the allowed volume of a 1U spacecraft. Therefore, there is no need for any mechanical deployment mechanism. This antenna is functionally equivalent to an omni-directional unity gain dipole.

The spacecraft is initially designed to enter safe mode for a period of approximately 2 hours post-deploy, to allow time to fully charge the batteries. The CubeSat will then exit safe mode and power up the processor which operates the RF system. The expected normal operation will wait 2.5 hours before any RF transmission. Once transmission begins, the CubeSat will transmit roughly every 31 seconds. These initial transmissions will have sufficient information to determine the health of the power system. Once the ground system confirms the safe state of the flight electronics, science operations can proceed. The torque system will then begin to regulate the spin rate of the spacecraft, as well as point the spin axis to within 30° of the North-South direction. The data gathered from the spacecraft can be used to compute a map of chlorophyll on a 200 km scale every few days

Materials

The CubeSat structure is made of aluminum. It contains standard commercial off the shelf (COTS) materials, electrical components, PCBs and solar cells.

Hazards

There are no pressure vessels, hazardous, or exotic materials.

Batteries

EdgeCube uses 3 NiCd batteries for power storage. The batteries will be recharged by solar cells mounted on the body of the satellite. The system used on EdgeCube is the same flown on the successful HETE2 mission.

Section 3: Assessment of Spacecraft Debris Released during Normal Operations

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.

The 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.

No releases are planned for EdgeCube, therefore this section is not applicable.

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 EdgeCube mission.

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 (h)).

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. (h))

Limitations in space and mass prevent the inclusion of the necessary resources to disconnect the battery or the solar arrays at EOM. However, the low charges and small battery cells on the CubeSat's power system prevents a catastrophic failure, so that passivation at EOM is not necessary to prevent an explosion or deflagration large enough to release orbital debris.

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4 shows that with a maximum CubeSat lifetime of 2.98 years maximum, EdgeCube is compliant.

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.

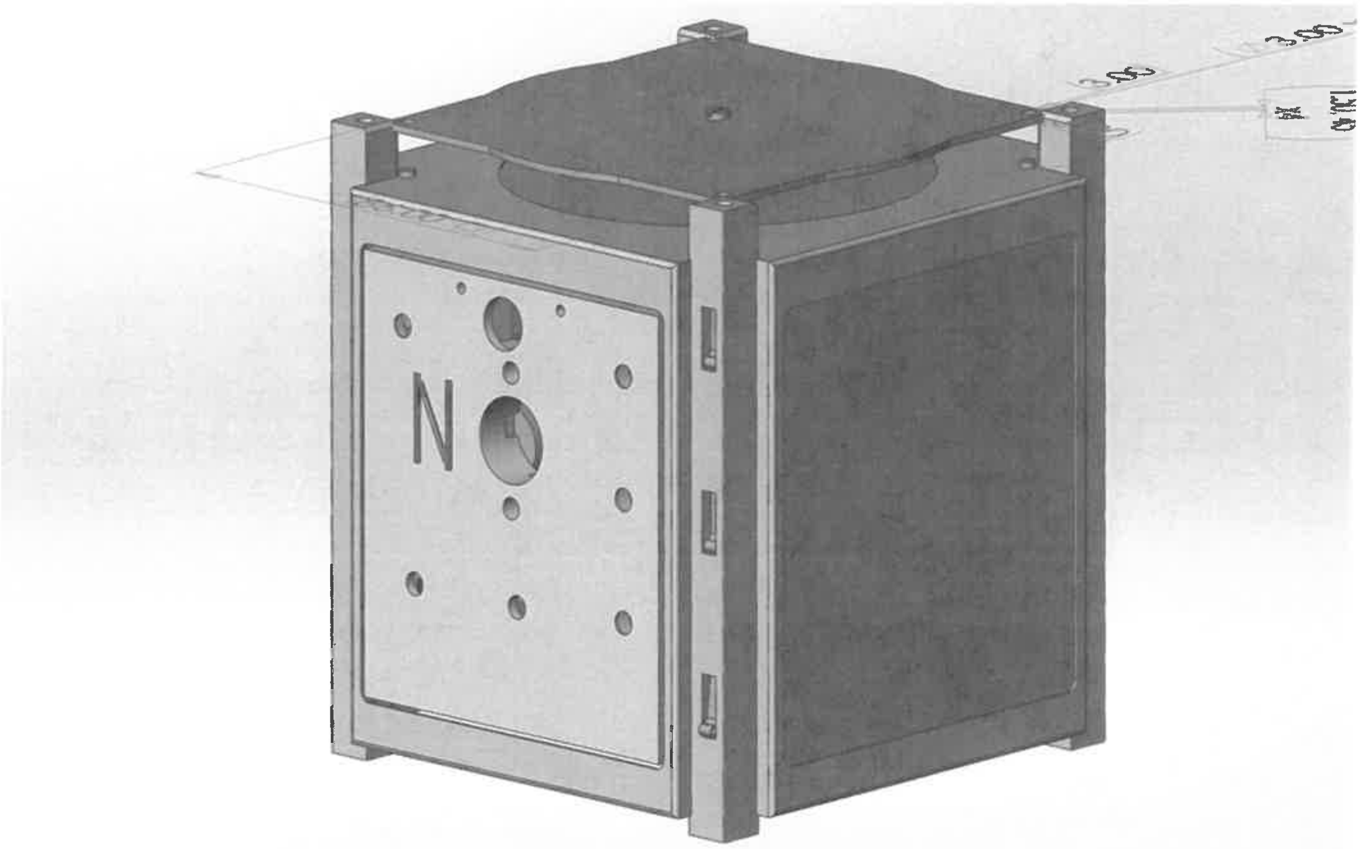

Figure 4: EdgeCube Assembled View (with fixed antenna formed by the top PC board)

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

Equation 1: Mean Cross Sectional Area for Convex Objects

$$\textbf{Mean CSA} = \frac{(A_{max} + A_1 + A_1)}{2}$$

Equation 2: Mean Cross Sectional Area for Complex Objects

The CubeSat evaluated for this ODAR are stowed in a convex configuration, indicating there are no elements of the CubeSat obscuring another element of the same CubeSat from view. Thus, the mean CSA for the CubeSat was calculated using Equation 1.

Refer to Appendix A for component dimensions used in these calculations

EdgeCube (1.48 kg) orbit at deployment will be 500 km at a 51.6° inclination. With an area to mass ratio of 0.01 m^2/kg, DAS yields 2.98 years for orbit lifetime for its stowed state, which in turn is used to obtain the collision probability. EdgeCube is calculated to have a probability of collision of 0.0. Table 3 below provides complete results.

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.

	CubeSat	EdgeCube
	Mass (kg)	1.48
Stowed	Mean C/S Area (m^2)	0.015
	Area-to Mass (m^2/kg)	0.010
	Orbital Lifetime (yrs)	**2.98**
	Probability of collision (10^X)	**0.0000**

Solar Flux Table Dated 12/18/2018

Table 3: CubeSat Orbital Lifetime & Collision Probability

The probability of EdgeCube colliding with debris and meteoroids greater than 10 cm in diameter and capable of preventing post-mission disposal is less than 0.00000, for any configuration. This satisfies the 0.001 maximum probability requirement 4.5-1.

Assessment of spacecraft compliance with Requirements 4.5-1 shows EdgeCube to be compliant.

EdgeCube has no capability or plans for end-of-mission disposal, therefore Requirement 4.5-2 is not applicable. EdgeCube will passively reenter and therefore this ODAR also serves as the EOMP (End of Mission Plan).

Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

EdgeCube 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 post-mission 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 finds EdgeCube in its stowed configuration as the worst case. The area-to-mass is calculated for is as follows:

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

Equation 2: Area to Mass

$$\frac{0.015\ m^2}{1.48\ kg} = 0.01\frac{m^2}{kg}$$

The assessment of the spacecraft illustrates they are compliant with Requirements 4.6-1 through 4.6-5.

DAS 2.1.1 Orbital Lifetime Calculations:
DAS inputs are: 500 km circular orbit with an inclination of 51.6° at deployment no earlier than January 2020. An area to mass ratio of ~**0.01** m^2/kg for the EdgeCube CubeSat was used. DAS 2.1.1 yields a 2.98 years orbit lifetime for EdgeCube in its stowed state.

This meets requirement 4.6-1. For the complete list of CubeSat orbital lifetimes reference **Table 3: CubeSat Orbital Lifetime & Collision Probability**.

Assessment results show compliance.

Section 7: Assessment of Spacecraft Reentry Hazards

A detailed assessment of the components of EdgeCube was performed. The assessment used DAS 2.1.1, 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 taking into account 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 components 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 possess the same negligible risk as stainless steel components.

Table 4: EdgeCube High Melting Temperature Material Analysis

CubeSat	Name	Material	Total Mass (kg)	Demise Alt (km)	Kinetic Energy (J)
EdgeCube	Primary Mounting Rods	Steel	.0036	76.6	0
EdgeCube	Secondary Mounting Rods	Steel	.003	77.0	0
EdgeCube	4-40 Nuts	Steel	.0005	76.7	0
EdgeCube	Antenna	Steel	.048	76.4	0
EdgeCube	Bottom Plate	Aluminum	.081	77.9	0

All of the high melting point material components demise upon reentry and EdgeCube complies with the 1:10,000 probability of Human Casualty Requirement 4.7-1.

Table 5: Requirement 4.7-1 Compliance for EdgeCube

Name	Status	Risk of Human Casualty
EdgeCube	Compliant	1:0

*Requirement 4.7-1 Probability of Human Casualty > 1:10,000

.

EdgeCube is shown to be in compliance with Requirement 4.7-1 of NASA-STD-8719.14A.

Section 8: Assessment for Tether Missions

EdgeCube will not be deploying any tethers.

EdgeCube satisfies Section 8's requirement 4.8-1.

Section 9-14

ODAR sections 9 through 14 pertain to the launch vehicle, and are not covered here. Launch vehicle sections of the ODAR are the responsibility of the CRS provider.

If you have any questions, please contact the undersigned at 321-867-2098.

/original signed by/

Yusef A. Johnson
Flight Design Analyst
a.i. solutions/KSC/AIS2

cc: VA-H/Mr. Carney
VA-H1/Mr. Beaver
VA-H1/Mr. Haddox
VA-C/Mr. Higginbotham
VA-C/Mrs. Nufer
VA-G2/Mr. Treptow
SA-D2/Mr. Frattin
SA-D2/Mr. Hale
SA-D2/Mr. Henry
Analex-3/Mr. Davis
Analex-22/Ms. Ramos

Appendix Index:

Appendix A. EdgeCube Component List:

Appendix A. EdgeCube Component List

Item Number	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter / Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (F°)	Survivability
1	EdgeCube Structure	1	Aluminum	Box	270	100	100	100	No	-	Demise
2	Solar Panels	3	Glass-Si	Box	187.5	85	80	5	No	-	Demise
3	Battery	3	NiCd	Box	60.6	48.5	14.5	14.4	No	-	Demise
4	NIR Colimators	1	Dalrin	Box	23.2	77.5	75	9.5	No	-	Demise
5	Primary Mounting Rods	4	Steel	Cylinder	14.4	3	100	3	Yes	2550°	Demise
6	Secondary Mounting Rods	10	Steel	Cylinder	30	3	88	3	Yes	2550°	Demise
7	4-40 Nuts	200	Steel	Cylinder	100	4.7	5.3	5	Yes	2550°	Demise
8	Power Board	1	Electronics	Box	16.6	85	40	1.5	No	-	Demise
9	S/C Monitor	1	Electronics	Box	24.4	85	40	1.5	No	-	Demise
10	Sensor Controller	1	Electronics	Box	24.8	85	40	1.5	No	-	Demise
11	Sensor Face	1	Electronics	Box	21.4	80	75	9.5	No	-	Demise
12	Torque Board	1	Electronics	Box	38.9	85	85	1.5	No	-	Demise
13	Battery Board	1	Electronics	Box	33.4	85	85	1.5	No	-	Demise
14	Copper Plate	1	Copper alloy	Box	411	85	85	0.84	No	-	Demise
15	S/C Controller	1	Electronics	Box	23.5	80	40	14	No	-	Demise
16	Torque Coils	2	Electronics		44.8	75	75	4	No	-	Demise
17	Aspect Camera	1	Steel/Electronics	Box	10.7	32	32	28	No	-	Demise
18	Camera Holder	1	Dalrin	Box	3	45	34	15	No	-	Demise
19	Antenna	1	Spring Steel	Box	48.7	10	340	6	Yes	2550°	Demise
20	Aluminum Bottom Plate	1	Aluminum	Plate	81	106	106	8.5	Yes	1221°	Demise
21	Flight Wire	12	Insulated Wire	-	7.2	1	20	1	No	-	Demise