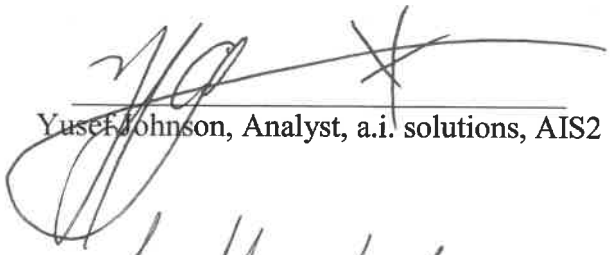
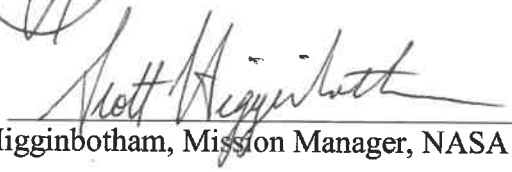
ELVL-2019-0045610
November 1, 2019

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

Signature Page



Yusef Johnson, Analyst, a.i. solutions, AIS2



Scott Higginbotham, Mission Manager, NASA KSC VA-C

National Aeronautics and
Space Administration

John F. Kennedy Space Center, Florida
Kennedy Space Center, FL 32899

ELVL-2019-0045610

Reply to Attn of: VA-H1

November 1, 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 CaNOP Mission

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 October 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 CaNOP CubeSat, which will be deployed from the International Space Station (ISS)

This report 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. Please note an original CaNOP ODAR was produced for the ELaNa-23 complement, reference ELVL-2016-004452 (August 2017).

RECORD OF REVISIONS		
REV	**DESCRIPTION**	**DATE**
0	Original submission	November 2019

Section 1: Program Management and Mission Overview

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

CaNOP: Kevin Crosby, Principal Investigator, Carthage College

The following table summarizes the compliance status of the CaNOP CubeSat to be deployed from the International Space Station. CaNOP 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 1.61 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 CaNOP

Program Milestone Schedule	
Task	Date
CubeSat Selection	August 16, 2016
Dispenser Integration	7/1/2020
Launch	10/1/2020
Deployment	NET 11/2020

Figure 1: Program Milestone Schedule

CaNOP will be launched as a payload on the Antares launch vehicle executing the NG-14 mission. CaNOP will be deployed from the International Space Station. CaNOP's attributes are identified in Table 2: Attributes

Section 2: Spacecraft Description

Table 2: Attributes outlines the generic attributes of the spacecraft.

Table 2: CaNOP Attributes

CubeSat Names	CubeSat Quantity	CubeSat size (mm^3)	CubeSat Masses (kg)
CaNOP	1	340 x 100 x 100	2.8

The following pages describe the CaNOP CubeSat

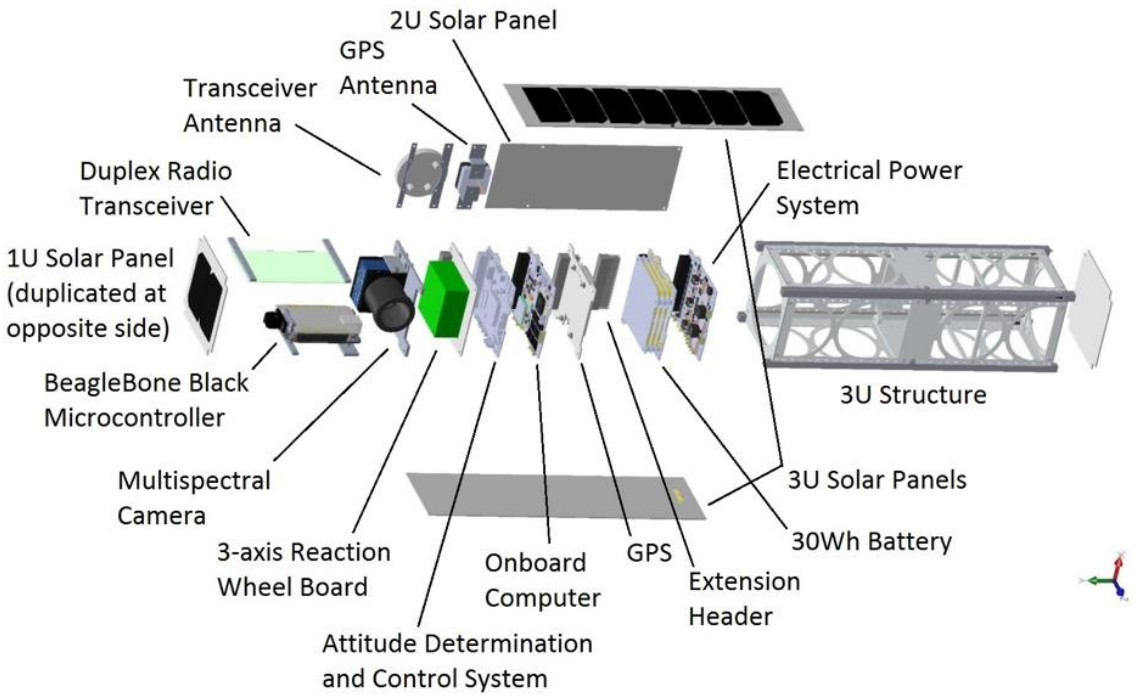


Figure 2: CaNOP Exploded View

Overview

The CaNOP CubeSat mission objective is to provide an educational experience in aerospace engineering to undergraduate students through designing, building, testing, and operating a 3U CubeSat designed to replicate early Landsat remote sensing capabilities. To achieve this objective, a multispectral linescan imaging sensor and associated optics capable of resolving a ground sample distance of 60 m and a scene size of 120 km will be utilized.

CONOPS

Upon deployment from the ISS, CaNOP will power up and attempt a status test of internal systems. After 45 minutes, the ADCS proceeds to de-tumble CaNOP . When CaNOP is approaching an imaging target, the camera will be activated. The camera will acquire spectrally resolved images along the orbital path. When CaNOP CubeSat is near a Near Earth Network (NEN) ground station with S-band capabilities, the communication system will be activated and begin transmitting handshake signals until downlink is established. Once downlink is established, compressed image data and telemetry will be broadcast to the closest ground station within range. When CaNOP is low on power the EPS will stop powering all unnecessary components and allow CaNOP to orbit until the 30 Whr battery has been sufficiently recharged

Materials

The CaNOP CubeSat components are commercial-off-the-shelf (COTS) materials, electrical components, and solar cells. The primary provider for COTS technology used in CaNOP is ClydeSpace, Inc.. The primary structural component is the 3U frame provided by ClydeSpace, Inc. The ClydeSpace 3U structure is machined from anodized 6061 aluminum.

Hazards

There are no pressure vessels, hazardous or exotic materials.

Batteries

The electrical power storage system consists of common lithium ion polymer (LiPo) cell batteries with over-charge, over-discharge, over-current, over-voltage, and under-temperature protection. The LiPo cells are qualified to NASA standards EP-Wi-032.

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 CaNOP, 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 CaNOP 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 prevent 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 1.61 years maximum, CaNOP 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.

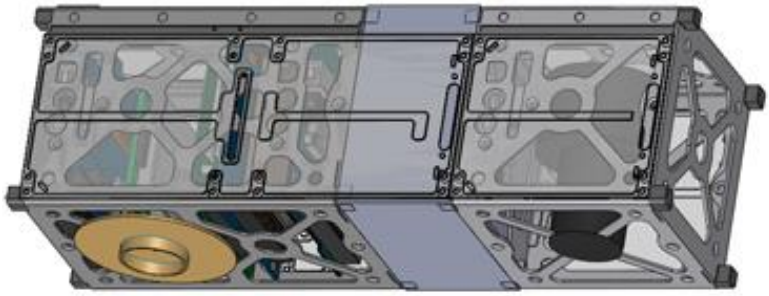


Figure 4: CaNOP View

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

Equation 1: Mean Cross Sectional Area for Convex Objects

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

Equation 2: Mean Cross Sectional Area for Complex Objects

The CubeSat evaluated for this ODAR is 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 stowed CubeSat was calculated using Equation 1. This configuration renders the longest orbital lifetime.

CaNOP (2.75 kg) orbit at deployment is 428 km by 409 km at a 51.6° inclination. With an area to mass ratio of 0.0098m^2/kg, DAS yields 1.61 years for orbit lifetime for its deployed state, which in turn is used to obtain the collision probability. CaNOP 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	CaNOP
Mass (kg)	2.75

Deployed	Mean C/S Area (m^2)	0.027
	Area-to Mass (m^2/kg)	0.0098
	Orbital Lifetime (yrs)	**1.61**
	Probability of collision (10^X)	**0.0000**

Solar Flux Table Dated
9/24/2019

Table 3: CubeSat Orbital Lifetime & Collision Probability

The probability of any CaNOP 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 CaNOP to be compliant. Requirement 4.5-2 is not applicable to this mission.

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

Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

CaNOP 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 CaNOP 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 3: Area to Mass

$$\frac{0.027\ m^2}{2.75\ kg} = \ 0.0098\frac{m^2}{kg}$$

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

<u>DAS 2.1.1 Orbital Lifetime Calculations:</u>
DAS inputs are: 428 km maximum apogee 409 km maximum perigee altitudes with an inclination of 51.6º at deployment no earlier than August 2020. An area to mass ratio of ~0.0098 m^2/kg for the CaNOP CubeSat was used. DAS 2.1.1 yields a 1.61 years orbit lifetime for CaNOP 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 CaNOP 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: CaNOP High Melting Temperature Material Analysis

Name	Material	Total Mass (kg)	Demise Alt (km)	Kinetic Energy (J)
Deployment Plunger Pin	Stainless Steel	.002	0	0
ADCS Reaction Wheels	Stainless Steel	.198	0	1
Hex Nuts	Steel	.050	0	0
Socket head screws	Black oxide alloy steel	.036	0	0
Ultra low profile socket head screws	Stainless Steel 304	.014	78.	-
Threaded Rod	Ti-6Al-4V	.040	0	0
Separation Springs	Stainless Steel	.002	0	0

The majority of high melting point components demise upon reentry and CaNOP complies with the 1:10,000 probability of Human Casualty Requirement 4.7-1. A breakdown of the determined probabilities follows:

Table 5: Requirement 4.7-1 Compliance by CubeSat

Name	Status	Risk of Human Casualty
CaNOP	Compliant	1:0

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

If a component survives to the ground but has less than 15 Joules of kinetic energy, it is not included in the Debris Casualty Area that inputs into the Probability of Human Casualty calculation. This is why CaNOP has a 1:0 probability, as none of their components have more than 15J of energy.

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

Section 8: Assessment for Tether Missions

CaNOP will not be deploying any tethers.

CaNOP 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. CaNOP Component List

Row Number	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter/ Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (Fº)	Survivability
1	CaNOP CubeSat 3U CubeSat	1	Al 6082	Box	2754	100	340	100	No	-	Demise
2	3U Solar Panel	2	PCB	Box	320	100	340	1.6	No	-	Demise
3	1U Solar Panel	2	PCB	Box	92	100	100	1.6	No	-	Demise
4	2U Solar Panel	1	PCB	Box	82	100	200	1.6	No	-	Demise
5	GPS Antenna	1	Copper alloy	Box	65	32	32	14	No	-	Demise
6	LS-GAT-17PP Antenna	1	Al 6061-T6	Cylinder	60	57.2	8.24	N/A	No	-	Demise
7	Rail X+Y+	1	Al 6082-T6	Box	35	5	340.5	10	No	-	Demise
8	Rail X-Y+	1	Al 6082-T6	Box	35	5	340.5	10	No	-	Demise
9	Rail X+Y-	1	Al 6082-T6	Box	35	5	340.5	10	No	-	Demise
10	Rail X-Y-	1	Al 6082-T6	Box	35	5	340.5	10	No	-	Demise
11	Shear Panel X-	1	Al 6082-T6	Box	28	1.5	340	100	No	-	Demise
12	Shear Panel X+	1	Al 6082-T6	Box	28	1.5	340	100	No	-	Demise
13	Shear Panel Y+	1	Al 6082-T6	Box	28	1.5	340	100	No	-	Demise
14	Shear Panel Y-	1	Al 6082-T6	Box	28	1.5	340	100	No	-	Demise
15	End Plate Z+	1	Al 6082-T6	Box	26	1.5	100	100	No	-	Demise
16	End Plate Z-	1	Al 6082-T6	Box	24	1.5	100	100	No	-	Demise
17	Stack Interface Rib	2	Al 6082-T6	Box	34	1.5	100	3	No	-	Demise
18	Fine Sun Sensors	3	Al 6082 Black Anodizing	Box	21	43	14	5.9	No	-	Demise
19	Deployment Plunger Pin	2	Stainless Steel	Cylinder	2	1.5	3	N/A	Yes	2500°	0 km
20	Camera Head	1	PCB	Box	205	52	46	53	No	-	Demise
21	ADCS Reaction Wheels	3	Stainless Steel	Cylinder	198	12	30	N/A	Yes	2500°	0 km
22	Clyde Space Battery Cell	6	Al	Box	180	37.5	60.5	5.4	No	-	Demise

23	Camera lens	1	Al (general)	Cylinder	135	46	44.1	N/A	No	-	Demise
24	Clyde Space 30 Whr Battery Board	1	PCB	Box	88	90.17	95.89	21.55	No	-	Demise
25	Clyde Space 3U EPS	1	PCB	Box	86	90.17	95.89	13.46	No	-	Demise
26	OBC	1	PCB	Box	62	90.17	95.89	1.6	No	-	Demise
27	Camera mount - plate	1	Al 6061	Box	55	90.17	95.89	3.2	No	-	Demise
28	hex nuts	50	steel	Cylinder	50	5.5	2.5	N/A	Yes	2500°	0 km
29	BeagleBone Black	2	PCB	Box	96	53.34	86.36	1.6	No	-	Demise
30	LinkStar Duplex- HD	1	PCB	Box	37	38.43	71.22	1.44	No	-	Demise
31	socket head screws	36	Black oxide alloy steel	Cylinder	36	3	14	N/A	Yes	2500°	0 km
32	aluminum spacers	36	Al 2011	Cylinder	36	4.5	15.24	N/A	No	-	Demise
33	BeagleBone Black Serial Cape	2	PCB	Box	66	55	93	13	No	-	Demise
34	GPS interface board	1	PCB	Box	50	90.17	95.89	1.6	No	-	Demise
35	NovAtel OEM719 (GPS Receiver)	1	PCB	Box	31	46	71	11	No	-	Demise
36	ADCS Mother Board	1	PCB	Box	25	90.17	95.89	7.46	No	-	Demise
37	ADCS Daughterboard	1	PCB	Box	25	90.17	95.89	44.49	No	-	Demise
38	Beagle Bone Black mount	1	Al 6061	Box	16	24	83	3.2	No	-	Demise
39	ultra low profile socket head screws	14	304 stainless steel	Cylinder	14	2.5	6	N/A	Yes	2500°	Demise
40	GPS antenna mount	1	Al 6061	Box	7	17	83	1.59	No	-	Demise
41	LinkStar Antenna Mount	1	Al 6061	Box	4	57.2	83	1.5	No	-	Demise
42	MLI	1	Polyamide	N/A	100	N/A	N/A	N/A	No	-	Demise
43	Hardware (assembly screws, standoffs, etc.)	1	Al (general)	N/A	60	N/A	N/A	N/A	No	-	Demise
44	Solar Panel Cabling	8	Copper alloy	Wire	40	4	40	N/A	No	-	Demise
45	Threaded Rod	4	Ti-6Al-4V	Cylinder	40	2	300	N/A	Yes	3034°	0 km
46	Ribbon Cabling	1	Copper alloy	Wire	20	20	60	N/A	No	-	Demise
47	Coaxial Cabling	2	Copper alloy	Wire	4	4	20	N/A	No	-	Demise
48	USB	2	Copper alloy	Wire	4	2	20	N/A	No	-	Demise

49	Camera mount - L brackets	1	Al 6061	Box	3	8	32.5	1.59	No	-	Demise
50	Separation Spring	2	Stainless Steel	Cylinder	2	1.5	3	3	Yes	2500°	0 km
51	Serial Connection	1	Copper alloy	Wire	1	4	10	N/A	No	-	Demise