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May 1, 2020

Orbital Debris Assessment for The SpaceICE CubeSat per NASA-STD 8719.14A

Signature Page

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ELVL-2019-0045713

Reply to Attn of: VA-H1

May 1, 2020

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 SpaceICE 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 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
I. ODPO Guidance Email: Fasteners and Screws, John Opiela to Yusef Johnson, 12 February 2020

The intent of this report is to satisfy the orbital debris requirements listed in ref. (a) for the SpaceICE CubeSat launching on the SpX-22 launch vehicle. 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 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 primary mission and are not presented here. This CubeSat will passively reenter, and therefore this ODAR also serves as the End of Mission Plan (EOMP) for this CubeSat.

RECORD OF REVISIONS		
REV	**DESCRIPTION**	**DATE**
0	Original submission	May 2020

Section 1: Program Management and Mission Overview

SpaceICE 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:

Dr. David Dunand, Principal Investigator, Northwestern University

The following table summarizes the compliance status of SpaceICE that will be flown on the SpX-22 mission to the International Space Station. SpaceICE 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 ~10 months
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 releases

Program Milestone Schedule	
Task	Date
CubeSat Selection	July 2019
Delivery to Nanoracks	January 2021
Launch	March 12, 2021

Figure 1: Program Milestone Schedule

SpaceICE will be launched as a payload on the Falcon 9 launch vehicle executing the SpX-22 mission. The current launch date is projected to be March 12, 2021

Section 2: Spacecraft Description

SpaceICE is flying as part of the ELaNa-36 mission complement. Table 2 outlines its generic attributes.

Table 2: SpaceICE Attributes

CubeSat Names	CubeSat Quantity	CubeSat size (mm^3)	CubeSat Mass (kg)
SpaceICE	1	321 x 100 x 100	3.1

The following pages describe the SpaceICE CubeSat.

SpaceICE – Northwestern University/ University of Illinois – 3U

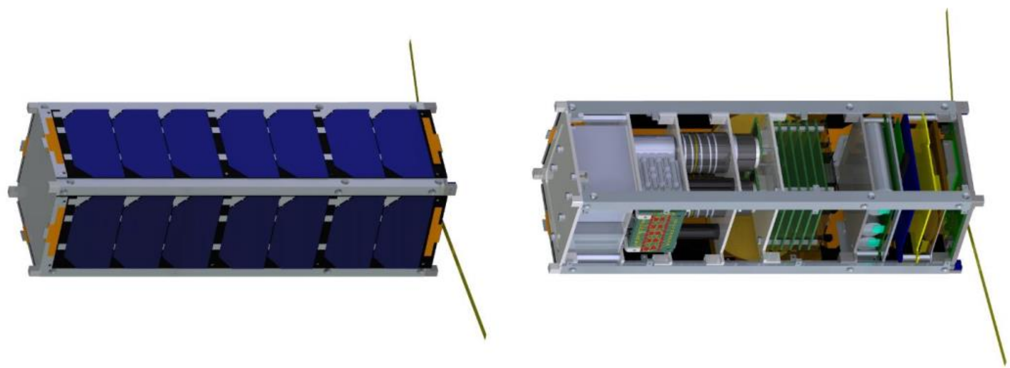

Figure 2: SpaceICE assembled and cutaway views

Overview

The SpaceICE mission aims to investigate the influence of gravity during directional solidification for the purpose of improving terrestrially based materials fabricated using the freeze-casting technique. The scientific payload consists of two aqueous particle suspension samples and one aqueous solution sample which will be repeatedly solidified (and melted) over the course of the mission. Scientific instrumentation includes: (i) cameras for imaging the solidification process and (ii) thermistors for in-situ temperature data acquisition during solidification. Data products include images and temperature data.

CONOPS

Following a successful launch and orbit insertion of the satellite, a detumbling maneuver utilizing magnetic torque coils will commence. Next, communications will be initiated with the UIUC ground station to verify satellite functionality. Once the satellite is in a stable configuration, bus functionality will be verified, and the spacecraft awaits an updated science schedule. When the system checks have been completed and the spacecraft has received the science schedule, the science mission phase begins.

During the science mission phase, the satellite's payload will conduct a series of experiments designed to investigate freeze-casting in the micro-gravity environment of Low Earth Orbit (LEO). Freeze-casting is a directional solidification technique that is used to fabricate porous materials with anisotropic, aligned pore structures. The SpaceICE mission aims to improve terrestrial fabrication of these materials by better understanding the role of gravity during the solidification process. To accomplish this, the spacecraft houses three cylindrical Pyrex containers which contain aqueous particle suspensions. Three cameras will capture still images of the experiment in order to observe the particle suspensions in various states. At the conclusion of a successful freeze-casting cycle, the satellite will package both science and health monitoring data for downlink.

The science mission phase will conclude after 26 weeks of successful experiments and science data retrieval, at which point the spacecraft enters the training and education phase for the remainder of its orbital lifetime. This final phase of the mission lifecycle will be utilized as a platform for students at Northwestern University, the University of Illinois, and Bradley University to gain hands-on experience operating the spacecraft, planning experiments, and analyzing data.

Materials

Satellite structure and solar panels are made from AL60601-T6. All aluminum is anodized, and the rails are Type III hard anodized. PCBs are made from FR-4, copper, and small electrical components. SpaceICE's payload has the same material make-up as the bus, along with Pyrex containers, and water/silver-coated glass bead suspensions.

Hazards

There are no pressure vessels, hazardous or exotic materials.

Batteries

The electrical power storage system consists of four lithium-ion batteries with over-charge, over-discharge, and over-current protection circuitry. The batteries are standard commercial LG Chem Lithium-Ion INR18650 MJ1 cells. The batteries will undergo flight acceptance testing in accordance with the procedures described in NanoRacks document NR-SRD-139 RevC "Flight Acceptance Test Requirements for Lithium-ion Cells and Battery Packs."

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 on the SpaceICE CubeSat, 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 for SpaceICE.

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 lifetime of ~10 months maximum, SpaceICE 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.

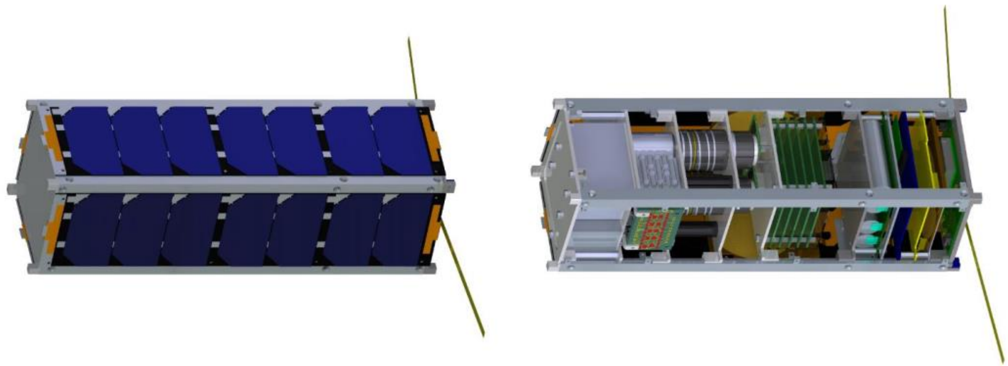

Figure 4: SpaceICE assembled and cutaway views

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

Equation 1: Mean Cross Sectional Area for Convex Objects

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

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 stowed CubeSat was calculated using Equation 1. This configuration renders the longest orbital life times for all CubeSats.

Once a CubeSat has been ejected from the CubeSat dispenser and deployables have been extended, Equation 2 is utilized to determine the mean CSA. A_{max} is identified as the view that yields the maximum cross-sectional area. A_1 and A_2 are the two cross-sectional areas orthogonal to A_{max}. Refer to Appendix A for component dimensions used in these calculations

SpaceICE's expected (~3.1 kg) orbit at deployment will have a 425 km apogee with a 412 km perigee. With an area to mass ratio of ~.009 m^2/kg, DAS yields ~10 months for orbit lifetime for its as-deployed state, which in turn is used to obtain the collision probability. SpaceICE was 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	SpaceICE
	Mass (kg)	3.088
As-deployed	Mean C/S Area (m^2)	0.02605
	Area-to Mass (m^2/kg)	0.00858
	Orbital Lifetime (yrs)	**~10 months**
	Probability of collision (10^X)	**0.00000**

*antennae area is negligible with respect to orbital lifetime calculations

Solar Flux Table Dated 1/16/2020

Table 3: CubeSat Orbital Lifetime & Collision Probability

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

SpaceICE has no capability or plans for end-of-mission disposal, therefore Requirement 4.5-2 is not applicable. SpaceICE 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

SpaceICE 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 among the CubeSats finds SpaceICE 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 3: Area to Mass

$$\frac{0.026\ m^2}{3.09\ kg} = \ 0.009\frac{m^2}{kg}$$

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

DAS Orbital Lifetime Calculations:
DAS inputs are: 425 km maximum apogee 412 km maximum perigee altitudes with an inclination of 51.6º at deployment no earlier than April 2021 An area to mass ratio of ~0.009 m^2/kg for the SpaceICE CubeSat was used. DAS yields an approximate 10 month (.838 year) orbit lifetime for SpaceICE in its as deployed state.

This meets requirement 4.6-1. For the orbital lifetime information, 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 to be flown on SpaceICE was performed. The assessment used DAS (Debris Analysis Software), 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.

3. Fasteners and similar materials that are composed of stainless steel or a lower melting point material will not be input into DAS, as suggested by guidance from the Orbital Debris Project Office (Reference I)

Table 4: SpaceICE High Melting Temperature Material Analysis

Name	Material	Total Mass (kg)	Demise Alt (km)	Kinetic Energy (J)
Antenna	Stainless steel	.018	0	.02
Dipole Antenna	Steel	.007	0	.55

The majority of stainless steel components demise upon reentry and SpaceICE 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
SpaceICE	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 all SpaceICE has a 1:0 probability, as none of its components have more than 15J of energy.

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

Section 8: Assessment for Tether Missions

SpaceICE will not be deploying any tethers.

SpaceIce satisfy 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
SA-D2/Mr. Frattin
SA-D2/Mr. Hale
SA-D2/Mr. Henry
Analex-3/Mr. Davis
Analex-22/Ms. Ramos

Appendix Index:

Appendix A. SpaceICE 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
-	SpaceICE	-	-	Box	3087	-	-	-	-	-	-
1	Bus-Rail	4	Aluminum 6061	Rail	193.44	17.00	17.00	321.00	-	-	Demise
2	Bus-Bottom Plate	1	Aluminum 6061	Plate	110.60	100.00	100.00	25.50	-	-	Demise
3	Bus-Antennae	4	Stainless Steel	Strip	17.60	6.70	22.00	0.40	Yes	2500°F	0 km
4	Bus-Short Radiation Shielding	2	Aluminum 6061	Plate	108.42	80.00	284.30	1.02	-	-	Demise
5	Bus-Tall Radiation Shielding	1	Aluminum 6061	Plate	69.27	80.00	327.00	1.02	-	-	Demise
6	Bus-Radiation Shielding with Access Port	1	Aluminum 6061	Plate	69.27	80.00	327.00	1.02	-	-	Demise
7	Bus-Solar Cell	25	Gallium Arsenide	Panel	85.50	40.00	70.00	0.40	-	-	Demise
8	Bus-Short Flex Cable	2	Kapton and PCB Components	Flat Cable	8.20	54.00	18.34	291.87	-	-	Demise
9	Bus-Tall Flex Cable	2	Kapton and PCB Components	Flat Cable	9.00	54.00	18.34	334.57	-	-	Demise
10	Bus-Top Plate	1	Aluminum 6061	Plate	76.30	100.00	100.00	25.50	-	-	Demise
11	Bus-Middle Plate	1	Aluminum 6061	Plate	65.30	93.65	93.65	13.50	-	-	Demise
12	Bus-Batteries	4	Lithium-Ion battery chemistry	Cylinder	184.40	18.40		65.00	-	-	Demise
13	Bus-Battery Support Plate	1	Aluminum 6061	Plate	25.20	86.00	86.00	2.00	-	-	Demise
14	Bus-Magnetometer	4	Circuit Board	Board	14.80	40.00	30.00	3.90	-	-	Demise
15	Bus-Daughter Card	1	Circuit Board	Plate	10.10	60.00	30.00	2.41	-	-	Demise
16	Bus-Power Board	1	Circuit Board	Board	56.50	94.00	90.00	1.50	-	-	Demise
17	Bus-C&DH Board (was CPU)	1	Circuit Board	Board	40.00	90.00	90.00	5.60	-	-	Demise
18	Bus-Torque Coil	6	FR-4	Plate	313.31	86.00	76.20	3.50	-	-	Demise
19	Bus-Torque Coil Plate	1	Aluminum 6061	Plate	17.80	74.00	74.00	1.00	-	-	Demise
20	Bus-GOMSPace Radio	2	Aluminum 6061	Plate	49.00	65.00	40.00	5.60	-	-	Demise
21	Bus-Radio Carry Board	2	Circuit Board	Board	38.20	60.00	90.00	1.60	-	-	Demise

22	Bus-RF Cable	1	Copper	Cylinder	4.40	4.00		150.00	-	-	Demise
23	Bus-Dipole Antenna	1	Steel	Plate	7.57	10.00	0.05	170.00	Yes	2500°F	0 km
24	Bus-M2.5 Solar Panel Screws 5.0mm	32	18-8 Stainless Steel	Cylinder	11.84	2.5		7.5	Yes	2500°F	Demise
25	Bus-M3.0 Rail Screws 6.0mm	48	18-8 Stainless Steel	Cylinder	21.6	3.00		8.00	Yes	2500°F	Demise
26	Bus- Antenna Brass Connector	1	Brass	Block	0.895	10.00	10.00	14.00	-	-	Demise
27	Bus-Lead Ballast	2	Lead	Block	317.6	20	70	10	-	-	Demise
28	Bus-Vibration Motor	2	Aluminum 6061 and PCB Components	Block	18.44	14	21.5	7.9	-	-	Demise
29	Bus-Vibration Motor Mount (Top)	1	Aluminum 6061	Block	29.49	30	59.68	6.59	-	-	Demise
30	Bus-Vibration Motor Mount (Bottom)	1	Aluminum 6061	Block	22.59	29.98	59.66	6.45	-	-	Demise
31	Bus-Vibration Motor Mount Standoffs	4	18-8 Stainless Steel	Hexagonal Prism	3.28	4.45	4.45	7.95	Yes	2500°F	Demise
32	Bus-Vibration Motor Board	1	Circuit Board	Flat Plate	10	50	50	10	-	-	Demise
33	Bus-Vibration Motor Screws	4	18-8 Stainless Steel	Hexheaded Screw	4.12	5.50	5.50	17.00	Yes	2500°F	Demise
34	Bus-Tall Standoffs	4	Aluminum 6061	Hexagonal Prism	6.48	4.50	4.50	20.00	-	-	Demise
35	Lenses	3	Aluminum/Glass	Cylindrical Tube	275.4	33	33	70	-	-	Demise
36	Sample Containers	3	Pyrex	Cylindrical Tube	20.7	18	2	40	-	-	Demise
37	Thermistor mount	3	Teflon	Cylindrical Tube	33	24	6	27	-	-	Demise
38	O-ring seal	3	Aluminum 6061	Cylindrical	10.8	15		11	-	-	Demise
39	Sample container mount	3	Teflon	Cylindrical	15	24		8	-	-	Demise
40	Mirrors	3	Aluminum 6061	Cylindrical	39	25		9.5	-	-	Demise
41	Circuit boards	7	Circuit board	Flat Plate	140	80	70	2	-	-	Demise
42	Camera Sensor	3	Circuit Board/Aluminum 6061	Box	43.5	34.1	24.4	9.3	-	-	Demise
43	Mirror Mounts, Sensor Board Mounts, Payload Support Plate	3	Aluminum 6061	Box	288.9	18	10	18	-	-	Demise
44	Payload Plate	3	Aluminum 6061	Flat Plate	171	93.7	93.7	2.5	-	-	Demise

45	Vented stainless steel screws (payload plates, sample containers, and mounts)	22	18-8 Stainless Steel	Cylinder	8.14	2.5		7.5	-	2500°F	Demise
46	Hex standoffs (circuit board connectors)	28	Aluminum	Cylinder	7.476	5	5		-	-	Demise
47	Payload plate rail screws, M3.0, 6.0mm	32	18-8 Stainless Steel	Cylinder	14.4	3.00		8.00	-	2500°F	Demise