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April 9, 2020

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

Signature Page

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ELVL-2020-0045760

Reply to Attn of: VA-H1

April 9, 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 BeaverCube 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
J. ODPO Guidance Email: Carbon Aerogel, Benton Greene to Yusef Johnson, 16 March 2020

The intent of this report is to satisfy the orbital debris requirements listed in ref. (a) for the BeaverCube CubeSat launching on the SpX-21 Falcon 9 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 will also serve as the End of Mission Plan (EOMP) for this CubeSat.

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

Section 1: Program Management and Mission Overview

BeaverCube 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:

Prof. Kerry Cahoy, Massachusetts Institute of Technology, Principal Investigator
Cadence Payne, Massachusetts Institute of Technology, Project Manager

The following table summarizes the compliance status of BeaverCube, which will be flown on the SpX-21 mission to the International Space Station. BeaverCube 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 1.34 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 releases

Program Milestone Schedule	
Task	**Date**
CubeSat Selection	August, 2019
Delivery to Nanoracks	July 1, 2020
Launch	October 30, 2020

Figure 1: Program Milestone Schedule

BeaverCube will be launched as a payload on the Space Falcon 9 launch vehicle executing the SpX-21 mission. The current launch date is projected to be October 30, 2020

Section 2: Spacecraft Description

BeaverCube is flying as part of the ELaNa-33 mission complement. Table 2 outlines its generic attributes.

Table 2: BeaverCube Attributes

CubeSat Names	CubeSat Quantity	CubeSat size (mm^3)	CubeSat Mass (kg)
BeaverCube	1	340 x 100 x 100	3.995

The following pages describe the BeaverCube CubeSat.

BeaverCube – Massachusetts Institute of Technology – 3U

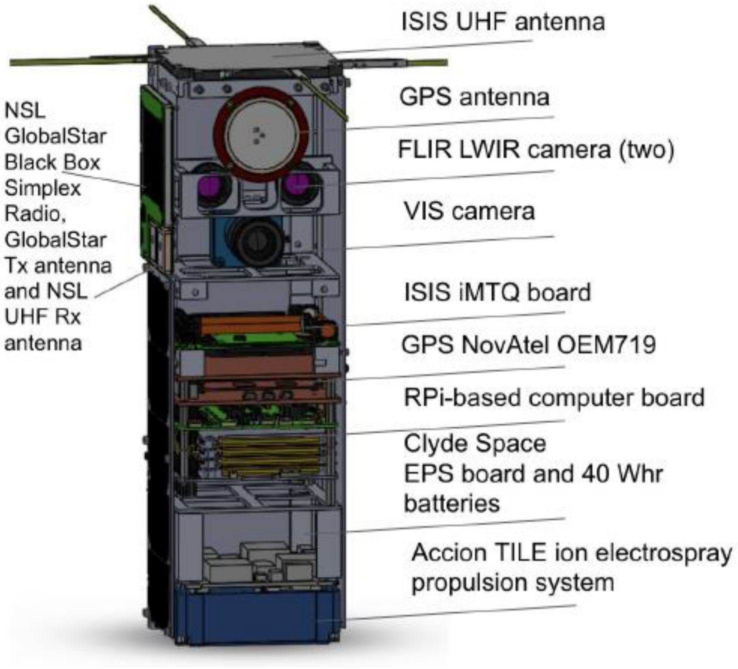

Figure 2: BeaverCube

Overview

BeaverCube has 3 objectives: First, BeaverCube will use two Long-Wave Infrared (LWIR) imagers to make measurements of cloud top temperature and sea surface Temperature. The second objective is that BeaverCube will measure ocean color using a Visual (VIS) camera. The third objective is that BeaverCube will demonstrate ion electrospray propulsion technology using the Accion Systems, Inc. Tiled Ionic Liquid Electrospray (TILE) propulsion technology.

CONOPS

Upon deployment from the dispenser, the mechanical separation switches will engage and allow BeaverCube to power its count-down clock. At no earlier than 45 minutes after deployment, the UHF antennas (ISIS CubeSat Antenna System) for the satellite OpenLST Radio (primary) will be deployed. The spacecraft will power up in safe mode. No sooner than 45 minutes after deployment, the NSL BlackBox radio will beacon at 1616.25 MHz to the GlobalStar constellation every 5 minutes. As soon as the MIT team establishes two-way communication with the Open LST UHF radio, the GlobalStar will beacon every 15 minutes or by command only. The satellite OpenLST UHF radio will downlink to the MIT ground station at 401.5MHz. The MIT ground station will uplink to the satellite at 450MHz. All uplink commands to the spacecraft will be encrypted to ensure security. After spacecraft check out, MIT will command BeaverCube to detumble. After imaging payload check out, BeaverCube will begin taking science images with the VIS and LWIR cameras. Due to power and data rate limitations, we will take and downlink pictures about once every 2 days initially. After propulsion payload check out, and only with approval from CSpOC and the ISS program, BeaverCube will conduct 3-hour translational propulsive maneuvers until a detectable altitude change (predicting less than 500 meters) is made to demonstrate functionality of the Accion TILE iEPS thruster unit.

Materials

The CubeSat structure is made of Aluminum 7075-T6. It contains all standard commercial off the shelf (COTS) materials, electrical components, PCBs that will be conformal coated with ISS-compatible coating, and solar panels. The Accion TILE propulsion system uses ionic liquid propellant that is sealed in liquid impermeable PEEK tanks. The secondary radio (also known as the GlobalStar BlackBox) has a ceramic patch antenna. The GPS receiver antenna is aluminum. The primary radio antenna is made of nickel-titanium alloy, but the housing is made of aluminum.

Hazards

BeaverCube's propulsion system includes 444.15 µL of ionic liquid propellant EMI-BF4 is stored in liquid impermeable PEEK (polyether ether ketone) tanks. Outlets of tanks are sealed with valves that are controlled via solenoid. Other access points (e.g. fill ports) are sealed with elastomeric seals with an additional liquid-impermeable epoxy sealant added for redundancy. The maximum pressure in the tanks is 30 psi. Liquid containment has been confirmed via qualification testing.

The propulsion system is a half unit system (9.202 cm x 9.202 cm x 5 cm). As shown in Figure 3 the system has a control board as well as thruster assemblies. The four thruster assemblies each include a propellant tank, an emitter chip, an extractor grid, and a propellant management system. These are housed inside the protective shield.

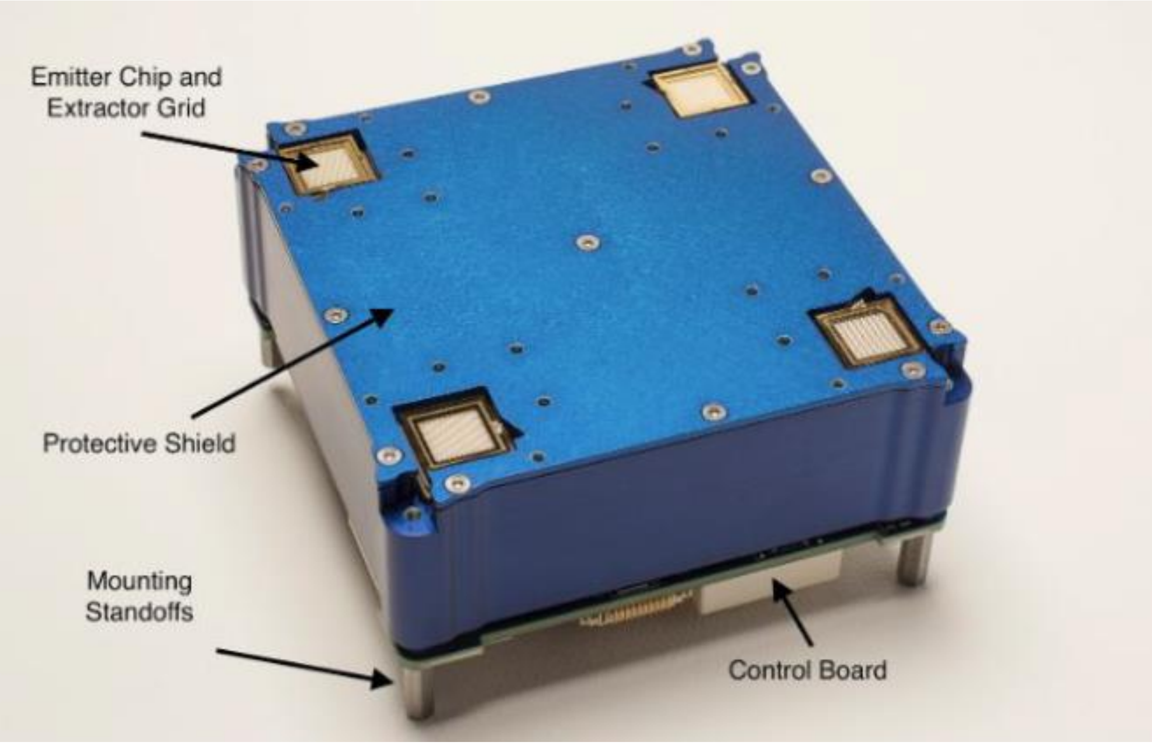

Figure 3: Accion TILE 2 electrospray system

The Accion TILE electrospray propellant system presents a unique set of features, and is detailed here in this section. The propellant tanks are constructed with liquid-impermeable, gas-impermeable PEEK (polyether ether ketone) with wall thickness of 1.93mm. During launch, storage, and deployment, the tanks are sealed by a solenoid actuated valve controlled by a microcontroller on the control board. Other access points (e.g. fill ports) are sealed with liquid-impermeable elastomeric seals and a liquid-impermeable, gas-tight epoxy sealant. The tanks are filled at atmospheric pressure, and the propellant is further pressurized via a spring. The maximum pressure of the propellant, while the valve is closed is 30 psia. Vibration and vacuum testing is performed to ensure proper ionic liquid isolation prior to integration and launch.

The tanks are expected to maintain this pressure until the system is dosed. Dosing is a one time process performed on orbit in which the valve is opened by a command from the microcontroller. Once the propellant valve is opened, the propellant flows out of the tank and is captured by a vaned Propellant Management Device (PMD). The PMD functions as a zero-g wick and makes use of the propellant's surface tension to deliver it to the chips. Once the propulsion system is on-orbit and the propellant valve is actuated, the system pressure is reduced to < 1 psia. Any gasses in the propellant are vented when the valve is opened and the propellant is exposed to the vacuum environment. Once the system is dosed some of the propellant is absorbed by glass microfiber disks, a carbon electrode, a PET wick, and the emitter chip, while additional propellant remains in liquid form and is retained by the PMD.

The tanks do not hold pressure for the entire life of BeaverCube. The tanks only hold pressure up until the dosing event. The tanks are not actively pressurized during firing. The pressurization is only present to keep the system secure during launch and prevent the thrusters from flooding/being exposed to ionic liquid before firing. In the unlikely event that all tanks rupture at the same time, the ionic liquid will be completely contained within the volume of the protective shield. As long as BeaverCube is operated within the temperature limits of the propulsion system, the pressure will not increase.

The propellant for the TILE 2 system is the ionic liquid 1-Ethyl-3-methylimidazolium tetrafluoroborate (EMI-BF4). 444.15 microliters of propellant are used in the system. EMI-BF4 is a poorly coordinated salt with a calculated vapor pressure of 1E-11 Torr and a melting point of 15C. This propellant also displays supercooling properties. The safety data sheet (SDS) of this propellant is available online.

The likelihood of releasing droplets of propellant is low, according to the propulsion system vendor. There are 111 microliters of propellant in each tank. For this propellant to be released as droplets there would need to be a catastrophic physical failure of the satellite in which the tanks are deconstructed. The propellant supercools, meaning that, under certain conditions, it can remain a liquid even as its temperature is lowered below the freezing point. If propellant is released, its possible that it would freeze and it's also possible that it would remain a liquid. The propellant is not expected to sublimate. If propellant were to be released it would persist for some period of time, before eventually being degraded by UV radiation and atomic oxygen. The timescales involved for this process to occur are unknown. The spacecraft team would expect smaller droplets to persist for less time than larger ones.

Batteries

The Clyde Space 3rd Generation electrical power system (EPS) uses a 335-gram, 40 Whr lithium-polymer battery assembly with over-charge/current protection circuitry. Clyde Space will deliver an ISS battery test report to MIT and NASA.
The NSL BlackBox GlobalStar radio also has one 8.14 Whr battery, which is a coin cell. NSL will beproviding MIT with a battery test report for NASA. The batteries will undergo flight acceptance testing in accordance with the procedures described in Nanoracks document NR-SRD-139 Rev C “Flight Acceptance Test Requirements for Lithium-ion Cells and Battery Packs”. The Clyde Space EPS 1642 battery is UL recognized. The BlackBox coin cell battery (BBCV2.MH50009 is also UL listed.

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 BeaverCube 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 BeaverCube.

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 1.34 years maximum, BeaverCube 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.

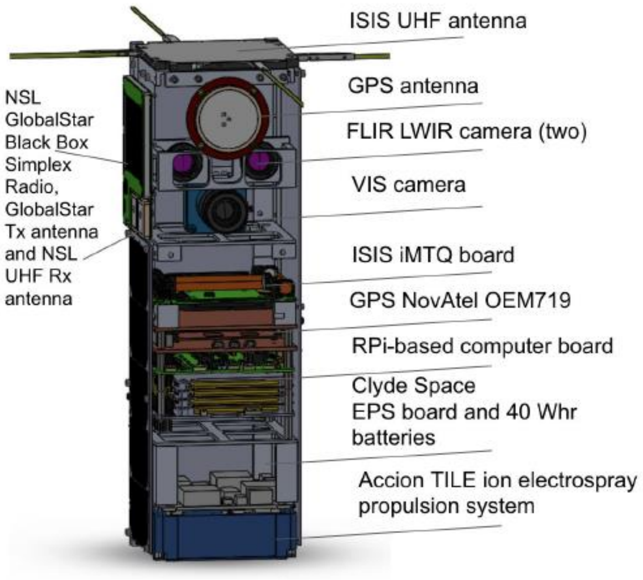

Figure 4: BeaverCube Assembled View

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

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 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 life times.

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

BeaverCube's (~4 kg) expected orbit at deployment from the ISS will have an apogee of 425 km and a perigee of 412 km. With an area to mass ratio of .0068 m^2/kg, DAS yields ~ 1.34 years for orbit lifetime for its stowed state, which in turn is used to obtain the collision probability. BeaverCube 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	**BeaverCube**
	Mass (kg)	3.995
Stowed	**Mean C/S Area (m^2)**	0.027
	Area-to Mass (m^2/kg)	0.006758
	Orbital Lifetime (yrs)	**1.34**
	Probability of collision (10^X)	**0.0000**

*deployable antenna area is negligible with respect to lifetime and collision calculations

Solar Flux Table Dated 1/16/2020

Table 3: CubeSat Orbital Lifetime & Collision Probability

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

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

BeaverCube 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 BeaverCube 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

$$\frac{0.027\,m^2}{3.995\,kg} = 0.0068\frac{m^2}{kg}$$

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

<u>Orbital Lifetime Calculations:</u>
DAS inputs are: 425 km maximum apogee 412 km maximum perigee altitudes with an inclination of 51.6º at deployment no earlier than October 2020. An area to mass ratio of ~0.0068 m^2/kg was used. DAS yields a 1.34 years orbit lifetime for BeaverCube 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 to be flown on BeaverCube 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 intends 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 during reentry. This 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. Fasteners and similar hardware that are composed of stainless steel or a lower melting point material will not be entered into DAS, as suggested by guidance from the Orbital Debris Project Office (Reference I)

2. 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.

3. 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 is expected to possess the same negligible risk as stainless steel components.

Table 4: BeaverCube High Melting Temperature Material Analysis

Name	Material	Total Mass (kg)	Demise Alt (km)	Kinetic Energy (J)
Patch Antenna	Ceramic	.016	76.4	-
Thruster Chip	Silicon	.044	77.8	-
Extractor	Silicon	.023	0	.01
M14 Filter	Silicon	.024	78.0	-
RTD	Platinum, ceramic	.010	0	.02
FLIR Camera VOx Sensor	Vandadium Oxide, Aluminum	*	*	*
Electrode, PMD	Carbon aerogel	.00026	*	*

* The vanadium oxide (VO_2) component contained in the FLIR camera's bolometer and the carbon aerogel that comprises the PMD electrode of the propulsion system are both components that fall outside of the material database contained within DAS. However, guidance has been obtained from the NASA Orbital Debris Project Office (ODPO)

(Reference J) that concluded the extremely small masses of these components would pose a corresponding small risk upon re-entry. Given the low ballistic number and very low mass, they will very likely have a terminal kinetic energy well below the threshold for human casualty risk.

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

BeaverCube is compliant with Requirement 4.7-1 of NASA-STD-8719.14A.

Section 8: Assessment for Tether Missions

BeaverCube will not be deploying any tethers.

BeaverCube 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. BeaverCube Component List:

Appendix A. BeaverCube 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	BeaverCube 3U		AL 7075-T6	Box	3995.6959	100	340	100	-	-	-
2	CubeSat Structure	1	Al 7075-T6	Box	330	100	340	100	No	-	Demise
3	Frame	1	Aluminum 6061	Box	6.5	82	100	7	No	-	Demise
4	Patch Antenna	2	Ceramic	Box	16	25	25	6	No	-	Demise
5	Top Solar PCB	1	FR4	Flat Slab	19	82	100	1	No	-	Demise
6	Batteries	1	Lithium Ion	Box	15	15	34	41	No	-	Demise
7	Main PCB	1	FR4	Flat Slab	60	82	100	1	No	-	Demise
8	Fasteners (#2-56)	7	SS18-8	Cylinder	2.1	5	9	N/A	No	-	Demise
9	Deployable Antenna	1	PCB substrate, NiTi-alloy SMA antenna, aluminum housing	Box	85	98	98	5.9	No	-	Demise
10	OpenLST Radio	1	FR4 PCB	Flat Slab	14	50	60	11.3	No	-	Demise
11	NovaTel GPS	1	FR4 PCB	Box	31	46	71	11	No	-	Demise
12	GPS Antenna	1	FR4 PCB	Flat Slab	120	143	N/A	30	No	-	Demise
14	ASSY, PROPULSION SUPPLY SYSTEM	4	- -	Box	142	20	20	20	No	-	Demise
15	ASSY, MEMS, THRUSTER CHIP	2	BOROSILICATE, SILICON, SPINODAL SILICA	Flat Slab	0.44	10	10	3	Yes	2577 °F	Demise
16	ASSY, MEMS, EXTRACTOR	1	SILICON (GOLD-COATED)	Flat Slab	0.23	10	10	3	Yes	2577 °F	0 km
17	ASSY, VALVE	1	PEEK, FKM, SST-18-8	Cylinder	6.36	25	25	1	No	-	Demise
18	ELECTRODE, PMD	1	CARBON XEROGEL	Cylinder	0.26	4.8	10	4.8	Yes	N/A	0 km
19	ASSY, PISTON CAP, CHERAX	1	PEEK	Cylinder	0.47	10	10	5	No	-	Demise
20	ASSY, TESTED, PCB, UTB INTERPOSER, CHERAX	1	370HR	Flat Slab	2.17	32	32	3	No	-	Demise

21	TANK BODY, UNI THRUSTER, CHERAX	1	PEEK	Box	20.6	40	40	35	No	-	Demise
22	VENTING SLEEVE, CHERAX	1	PTFE, POROUS	Cylinder	0.5	10	10	8	No	-	Demise
23	TANK CAP, CHERAX	1	PEEK	Flat Slab	0.47	16	16	2	No	-	Demise
24	PROPELLANT, IL-0006-HP-XXXX	444.2	EMI-BF4	N/A	0.57295	N/A	N/A	N/A	No	-	Demise
25	EPOXY, LOW OUTGAS, NO VOC, GEN PURP	0.01	Expoxy (Protavic ANE-46505)	N/A	0.46	N/A	N/A	N/A	No	-	Demise
26	EPOXY, LOW OUTGAS, NO VOC, GEN PURP	0.01	Epoxy (Masterbond 42HT-2AO-1 Black)	N/A	0.05	N/A	N/A	N/A	No	-	Demise
27	SYSTEM SHIELD and BRKT, MNT, THRUSTER HEAD	1	AL 7075 (ANNODIZED)	Box	33.16	92.02	92.02	30	No	-	Demise
28	ASSY, TESTED, PCB, ELITE	1	PARYLENE COATED	Flat Slab	121.28	92.02	92.02	20	No	-	Demise
29	Clyde Space Starbuck-Nano EPS	1	Aluminum	Box	86	90.17	95.89	16.2	No	-	Demise
30	Clyde Space Optimus-40 Battery	1	Lithium Polymer	Box	335	90.17	95.89	27.35	No	-	Demise
31	3U Solar Panel	3	PCB substrate, Kapton overlay	Flat slab	384	100	300	N/A	No	-	Demise
32	2U Solar Panel	1	PCB substrate, Kapton overlay	Flat slab	85.3	200	300	N/A	No	-	Demise
33	i-MTQ ADCS Board	1	FR4	Box	196	90	95	24	No	-	Demise
34	FLIR Boson Imaging Camera w/ Lens	2	Vanadium Oxide Sensor, Aluminum Housing		48	21	21	11	Yes	various	0 km
35	VIS Camera	1	Aluminum housing	Box	80	39.8	39.8	16.5	No	-	Demise
36	Kowa LM16JC 2/3" 16mm F1.4 Manula IRIS C-mount Lens (Lens for VIS Camera)	1	Aluminum housing	Cylinder	57	28.5	N/A	28	No	-	Demise
37	M14 Filter ThorLabs	1	Silicon	Cylinder	24	24.5	N/A	3	Yes	2577 °F	Demise
38	M16 Filter EOC	1	Germanium	Cylinder	14	30	N/A	3	No	-	Demise
39	Raspberry Pi Compute 3 Lite (CM3L)	2	PCB Substrate	Flat Slab	24	30	67.6	3.7	No	-	Demise
40	C&DH Board	1	FR4	Flat Slab	160	90	96	1.6	No	-	Demise
41	RTD	5	Platinum on alumina substrate, ceramic case, Teflon case	Box	10	4.8	8.0	2.0	No	-	Demise
42	Heater	5	Kapton	Flat Slab	1.75	19.1	63.5	0.2	No	-	Demise

43	Thermal Control Board	1	FR4	Box	100	90.0	96.0	1.6	No	-	Demise
44	Fasteners	100	18-8 SS	Cylinder	4	400	4.5	6.5	No	-	Demise
45	Connectors	30	Copper Alloy, PTFE	Cable	5	150	Various	N/A	No	-	Demise