ELVL-2019-0045664
December 18, 2019

Orbital Debris Assessment for The CubeSats on the Alpha CubeSat per NASA-STD 8719.14A

Signature Page

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ELVL-2019-0045664

Reply to Attn of: VA-H1

December 18, 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 Alpha 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 Alpha CubeSat launching on the SpaceX-21 Falcon 9 launch vehicle, as part of the ELaNa-31 complement. 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 2019

Section 1: Program Management and Mission Overview

The Alpha CubeSat 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:

The following table summarizes the compliance status of the Alpha CubeSat to be flown on the SpaceX-21 mission to the International Space Station, as part of the ELaNa-31 complement. The Alpha CubeSat is fully compliant with all applicable requirements.

Table 1: Orbital Debris Requirement Compliance Matrix

Requirement	Compliance Assessment	Comments
4.3-1a	Compliant	No planned debris release
4.3-1b	Compliant	No planned debris release
4.3-2	Compliant	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 yr
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 30, 2019
Delivery to Nanoracks	June 1, 2020
Launch	August 5, 2020

Figure 1: Program Milestone Schedule

The Alpha CubeSat will be launched as a payload on the Falcon 9 launch vehicle executing the SpaceX-21 mission to the International Space Station. Alpha's attributes are identified in Table 2: Alpha attributes

Section 2: Spacecraft Description

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

Table 2: Alpha Attributes

CubeSat Names	CubeSat Quantity	CubeSat size (mm^3)	CubeSat Masses (kg)
Alpha	1	113.5 X 100 X 100	1.6

The following pages describe the Alpha CubeSat.

Alpha - Cornell University – 1U

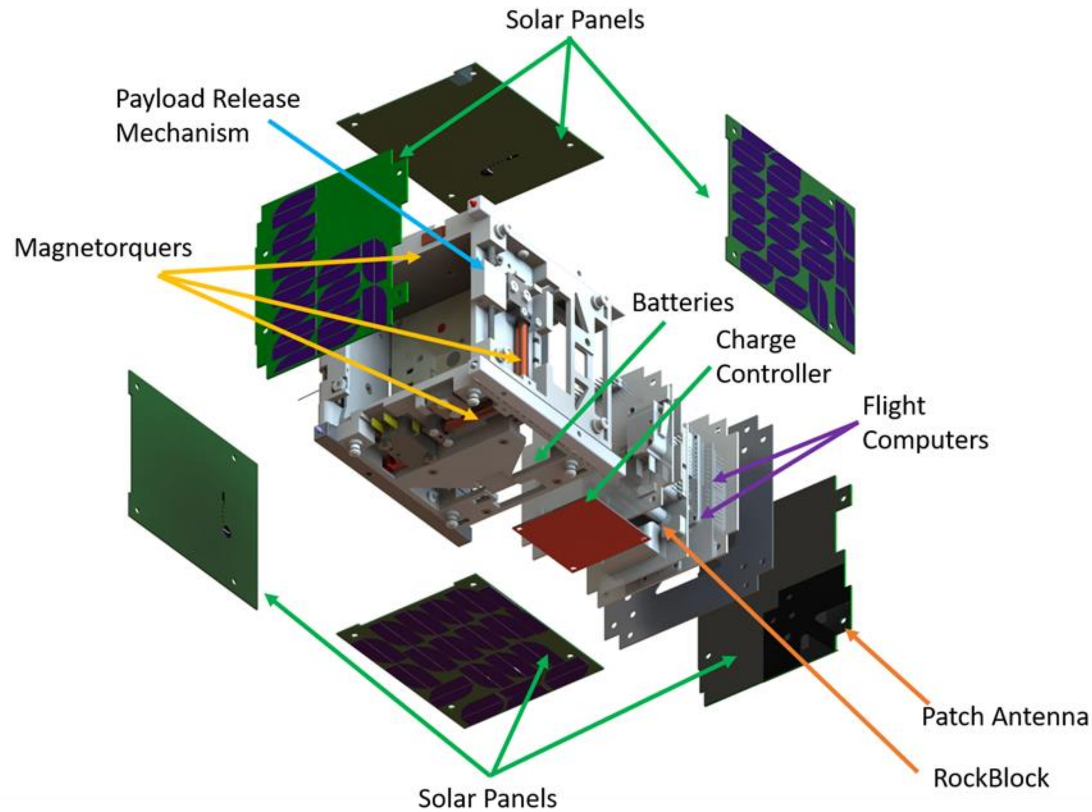

Figure 3: Alpha CubeSat exploded view

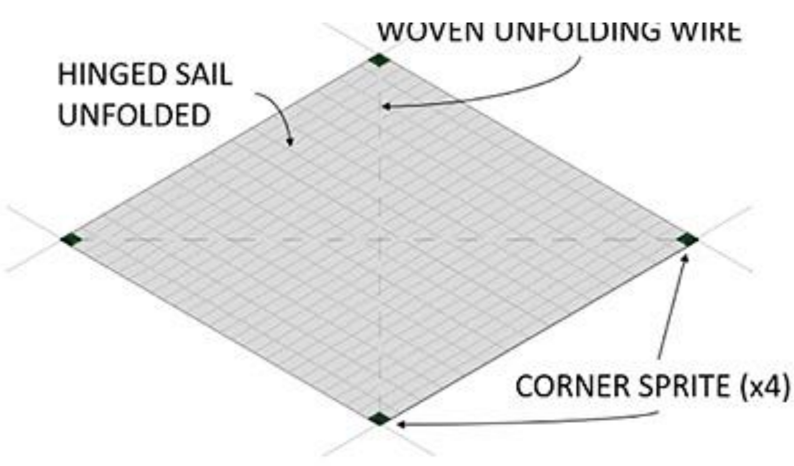

Figure 4: Alpha solar sail deployed view

Overview

Alpha comprises a 1U CubeSat capable of deploying a free-flying 1m x 1m light sail in response to ground commands. The sail is made of thin polycarbonate with a sensor-equipped ChipSat attached to each of the 4 corners. The overall goal of the Alpha mission is to serve as a technical demonstration of a light sail in orbit, verifying the properties of a highly retroreflective material for laser propulsion. Also, the sail architecture will demonstrate key functions of next-generation ChipSats, raising their TRL to 7. This mission highlights the versatility and adaptability of rapid design and prototyping with additive manufacturing.

CONOPS

After a minimum of 2 hours from deployment (plus additional time needed to reach Region 2), the Alpha CubeSat's transmitter will be powered on. A patch antenna is externally mounted, so no antenna deployment is necessary. The solar sail will be deployed on command no earlier than 3 weeks after CubeSat deployment from the ISS, and the receivers on the attached ChipSats will immediately power on. The CONOPS regarding conditions for sail deployment is under review with the International Space Station Program. Once over Region 2 (as determined by the onboard GPS), the ChipSats will begin transmitting. Within an estimated 1 to 3 days, the sail will deorbit due to its high ballistic coefficient. The CubeSat will deorbit after approximately 1 year from ISS deployment.

Materials

The rails of the CubeSat are fabricated from 7075 Aluminum. The remainder of the structure is 3D-printed Accura® Bluestone™, a nano-composite with high stiffness and thermal resistance. The CubeSat contains all standard commercial off the shelf (COTS) materials, electrical components, PCBs and solar cells. The high-speed radio uses a ceramic patch antenna.

The payload is manufactured from a thin polycarbonate film, with Nitinol wire to guide the unfolding. Both the ChipSats and PCBs on board the CubeSat are assembled with COTS components, and composed of copper, solder mask, silkscreen, and fiberglass substrate (FR4).

Hazards

There are no pressure vessels, hazardous or exotic materials.

Batteries

The electrical power storage system consists of common lithium-ion batteries with over-charge/current protection circuitry. The lithium batteries carry the UL-listing number MH10008.

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.

Alpha has a deployable solar sail, with four embedded 'ChipSats'. These will begin transmitting data immediately upon deployment. The sail is 1 m^2 in area and weighs 0.1776 kg. The sail will deploy by command no earlier than 3 weeks after the Alpha's ejection from the International Space Station. The expected orbit at sail deploy is 416 km x 404 km. The expected lifetime for the sail once it is deployed is approximately 3 days. The CONOPs regarding conditions for sail deployment is under review with the ISS Program.

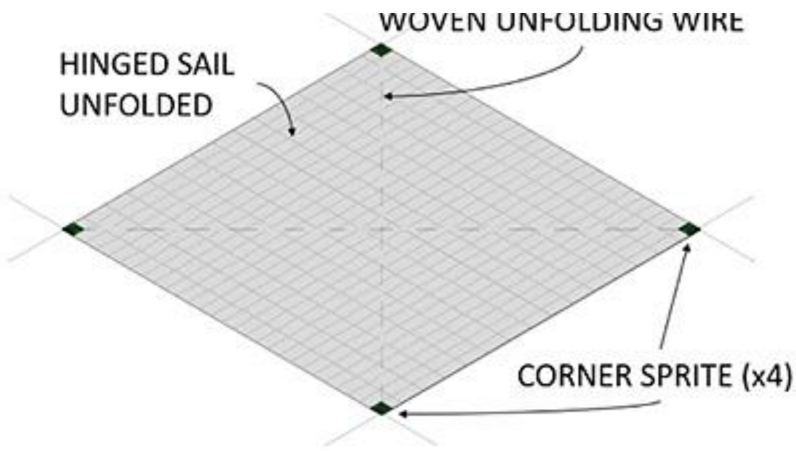

Figure 5: Deployed solar sail

The Alpha ChipSats and solar sail are compliant 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 for the Alpha 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 (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 year maximum, the Alpha CubeSat 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.

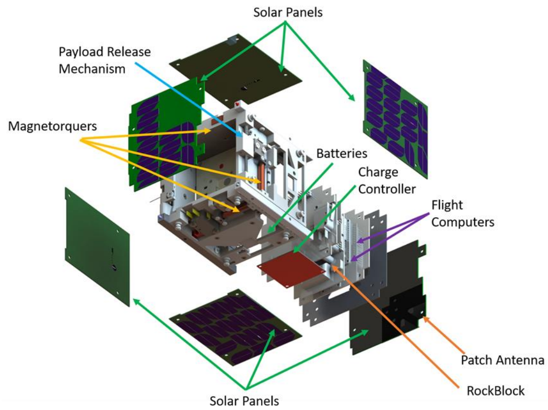

Figure 6: Alpha exploded view

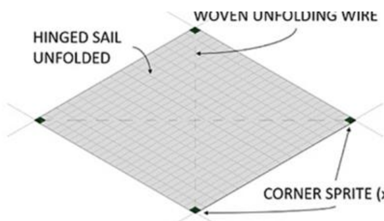

Figure 7: Deployed sail

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

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 CubeSat without deployables activated was calculated using Equation 1. This configuration renders the longest orbital life time for the Alpha CubeSat.

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

Alpha (1.6 kg) orbit at deployment is approximately a 427 km apogee with a 412 km perigee. With an area to mass ratio of .0115 m^2/kg, DAS yields ~1 year for orbit lifetime for its as stowed state, which in turn is used to obtain the collision probability. The Alpha CubeSat 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		Alpha
	Mass (kg)	1.6

As Stowed *	**Mean C/S Area (m^2)**	0.0183
	Area-to Mass (m^2/kg)	0.0115
	Orbital Lifetime (yrs)	**~1.0**
	Probability of collision (10^X)	**0.0000**

Deployed Sail	**Mean C/S Area (m^2)**	1
	Area-to Mass (m^2/kg)	5.63
	Orbital Lifetime (yrs)	**0.011**
	Probability of collision (10^X)	**0.0000**

Solar Flux Table Dated 9/24/2019

*** the difference in Alpha orbital lifetime calculations between the sail stowed and the sail deployed is negligible.**

Table 3: CubeSat Orbital Lifetime & Collision Probability

The probability of the Alpha CubeSat having a 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 Alpha to be compliant. Requirement 4.5-2 is not applicable to this mission.

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

The Alpha CubeSat 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 ratio for the post-mission disposal configuration finds Alpha with its deployables still stowed as the worst case Area-to-Mass. Which generates the longest orbital lifetime. 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

$$\frac{0.0183\, m^2}{1.60 kg} = \ 0.0115\frac{m^2}{kg}$$

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: 427 km maximum apogee 412 km maximum perigee altitudes with an inclination of 51.6º at deployment no earlier than September 2020. An area to mass ratio of ~0.0115 m^2/kg for the Alpha CubeSat was used. DAS 2.1.1 yields an approximate 1 year orbit lifetime for Alpha without any deployables activated.

The sail is 1 m^2 in area and weighs 0.1776 kg which yields an area to mass ratio of 5.63 m^2/kg. The sail is expected to be deployed no earlier than 3 weeks after the Alpha's ejection from the ISS. The expected orbit at sail deploy is 416 km x 404 km. The expected lifetime for the sail once it is deployed is approximately 3 days. The CONOPs regarding conditions for sail deployment is under review with the ISS Program.

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 the Alpha CubeSat 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: Alpha High Melting Temperature Material Analysis

Name	Material	Total Mass (kg)	Demise Alt (km)	Kinetic Energy (J)
Torsion Spring	Stainless Steel 316	.000637	75.2	-
Pan Head Screw 4-40	Stainless Steel 316	.000862	75.0	-
Hex Nut 4-40	Stainless Steel 316	.00080	74.3	-
Steel Compression Spring	A228 Steel	.0003	77.7	-
F/F Hex Standoff	18-8 Stainless Steel	.0248	0	0
M/F Hex Standoff	18-8 Stainless Steel	.0072	75.9	-
Master Stack M2_12 mm SS Flat head screw	18-8 Stainless Steel	.000062	77.8	-
Hub Pan Head Screw	Stainless Steel 316	.0044	77.6	-
Hub Hex Nut	Stainless Steel 316	.00319	77.6	-
Solar Panel Hex Nut	Stainless Steel 316	.00319	77.6	-
Solar Panel Pan Head Screw	Stainless Steel 316	.0064	77.8	-
Inhibitor Thin Hex Nut	Stainless Steel 316	.00174	0	0
Inhibitor PEM Nut	Stainless Steel 316	.000473	76.2	-

Inhibitor Flat Machine Screw	A2 Stainless Steel	.00415	75.8	-
Power Hex Nut	Stainless Steel 316	.0016	0	0
Power Flat Head Screw	Stainless Steel 316	.00145	75.8	-
Magnetorquer	Mu Metal	.031	0	0
M3_14 mm Screw	18-8 Stainless Steel	.0144	77.7	-
M3_12 mm Screw	18-8 Stainless Steel	.0156	77.8	-
M3_14 mm Screw	18-8 Stainless Steel	.000348	77.6	-
M3 Nut	18-8 Stainless Steel	.00022	0	0
M2 Nut	18-8 Stainless Steel	.00008	77.9	-
Weights M2_12mm Flat Head Screw	18-8 Stainless Steel	.0000624	77.8	-

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

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

Section 8: Assessment for Tether Missions

Alpha will not be deploying any tethers.

Alpha 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. Alpha 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	Alpha - 1U CubeSat		Rails: Al 6061 T6; Remainder of chassis: Accura® Bluestone™	Box	1600.771895	110	113.5	1600.771895	No	-	-
2	Torsion Spring	2	316 Stainless Steel	Cylinder	0.63651	4.4	6.3	0.63651	Yes	2500°	Demise
3	Pan Head Screw, 4-40, 316 Stainless Steel, 3-16 inch length	2	316 Stainless Steel	Cylinder	0.8615	1.5	6.6	0.8615	Yes	2500°	Demise
4	Hex Nut, 4-40, 316 Stainless Steel	2	316 Stainless Steel	Cylinder	0.7997	7.34	1.8	0.7997	Yes	2500°	Demise
5	Rod for Door Hinge	1	Carbon Fiber	Cylinder	0.90001	3	82	0.90001	No	-	Demise
6	Rod for Door Lock	1	Carbon Fiber	Cylinder	0.69147	3	63	0.69147	No	-	Demise
7	Steel Compression Spring	1	Music Wire (ASTM A228)	Box	0.3	4	35	0.3	Yes	2500°	Demise
8	Door Sensor (on door)	1	Copper	Plate	0.324	6	12	0.324	No	-	Demise
9	Door Sensor (on chassis)	2	Copper	Plate	0.324	6	6	0.324	No	-	Demise
10	Door Hinge	1	Accura® Bluestone™	Box	5.6	17.8	55.3	5.6	No	-	Demise
11	Lock for Door	1	Al 6061 T6	Box	2.39611	16.9	20	2.39611	No	-	Demise
12	Nylon Wire	1	Nylon	Cylinder	0.1	0.7	200	0.1	No	-	Demise
13	Nichrome Wire	1	Nichrome	Cylinder	0.03	0.3	50	0.03	No	-	Demise
14	Board for Stack Assembly	2	PCB: FR4, Copper, Plastic [CONFORMAL COATING - ARATHANE 5753]	Board	95.460264	84	89.5	95.460264	No	-	Demise
15	Teensy 3.5	1	PCB: FR4, Copper, Plastic [CONFORMAL COATING - ARATHANE 5753]	Board	9.1	18	62.3	9.1	No	-	Demise

16	microSD card	1	Silicone, Plastic, Gold [CONFORMAL COATING - ARATHANE 5753]	Board	0.25	11	15	0.25	No	-	Demise
17	SparkFun Motor Driver H-Bridge	1	PCB: FR4, Copper, Plastic [CONFORMAL COATING - ARATHANE 5753]	Board	0.14001	20.32	20.32	0.14001	No	-	Demise
18	Adafruit INA 169 Current Sensor	1	PCB: FR4, Copper, Plastic [CONFORMAL COATING - ARATHANE 5753]	Board	1.49994	20.27	22.86	1.49994	No	-	Demise
19	IMU LSM9DS1	1	PCB: FR4, Copper, Plastic [CONFORMAL COATING - ARATHANE 5753]	Board	2.80001	19.78	33	2.80001	No	-	Demise
20	Transistor	1	Silicone, Plastic, Copper [CONFORMAL COATING - ARATHANE 5753]	Box	0.05	7	15	0.05	No	-	Demise
21	RockBlock MK.II	1	PCB: FR4, Copper, Plastic [CONFORMAL COATING - ARATHANE 5753]	Board	71.79299	51.1	76	71.79299	No	-	Demise
22	Deployment Switch - Short	1	PCT Polyester/Aluminum/ Silver [CONFORMAL COATING - ARATHANE 5753]	Box	6.90082	20.3	37.8	6.90082	No	-	Demise
23	F/F Hex Standoff, 18-8 Stainless Steel, M3 Thread, 31 mm length	4	18-8 Stainless Steel	Cylinder	24.79988	6.93	31	24.79988	Yes	2500°	0 km
24	Spacer, M3, Ultem, 6mm OD, 3.135 mm length	4	Ultem® (polyetherimide)	Cylinder	0.80156	6	3.14	0.80156	No	-	Demise
25	M/F Hex Standoff, 18-8 Stainless Steel, M3 Thread, 8 mm length	4	18-8 Stainless Steel	Cylinder	7.19992	6.93	12.7	7.19992	Yes	2500°	Demise
26	Maxtena Iridium Patch Antenna	1	PCB: FR4, Copper, Plastic	Box	14.11	45	45	14.11	No	-	Demise

			[CONFORMAL COATING - ARATHANE 5753]								
27	M2_12mm Metric 18-8 SS Flat Head Phil Machine Screw	2	18-8 Stainless Steel	Cylinder	0.0624 4	2	12	0.06244	No	-	Demise
28	Antenna Brackets	2	Accura® Bluestone™	Plate	0.42	3	20	0.42	No	-	Demise
29	Alpha Hub	1	Accura® Bluestone™	Box	270	80	94.5	270	No	-	Demise
30	Rail 1	1	Al 6061 T6	Box	18.5	8.5	113.5	18.5	No	-	Demise
31	Rail 2	1	Al 6061 T6	Box	18.76	8.5	113.5	18.76	No	-	Demise
32	Rail 3	1	Al 6061 T6	Box	21.3	8.5	113.5	21.3	No	-	Demise
33	Rail 4	1	Al 6061 T6	Box	22.4	8.5	113.5	22.4	No	-	Demise
34	Bottom Mount Plate	1	Al 6061 T6	Plate	16.16	100	100	16.16	No	-	Demise
35	Pan Head Screw 4-40, 316 Stainless Steel	8	316 Stainless Steel	Cylinder	4.4	2.8	9.9	4.4	Yes	2500°	Demise
36	Hex Nut, 4-40, 316 Stainless Steel	8	316 Stainless Steel	Cylinder	3.192	7.34	1.8	3.192	Yes	2500°	Demise
37	Side Boards	4	PCB: FR4, Copper, Plastic [CONFORMAL COATING - ARATHANE 5753]	Board	317.77 92	83	100	317.779 2	No	-	Demise
38	Top/Bottom Boards	2	PCB: FR4, Copper, Plastic [CONFORMAL COATING - ARATHANE 5753]	Board	158.49 92	91	100	158.499 2	No	2500°	Demise
39	Litiholo 2.0 Instant Holograms	6	C-RT20 Film, Polycarbonate [CONFORMAL COATING - ARATHANE 5753]	Plate	0.6	50	50	0.6	No	-	Demise
40	Hex Nut, 4-40, 316 Stainless Steel	16	316 Stainless Steel	Cylinder	6.3976	7.34	1.8	6.3976	Yes	2500°	Demise
41	Pan Head Screw, 4-40, 316 Stainless Steel, 3-8 inch length	16	316 Stainless Steel	Cylinder	1.712	2.8	11.43	1.712	Yes	2500°	Demise
42	Solar Cells	132	Triple Junction GaAs [CONFORMAL	Plate	23.1	7	26	23.1	No	-	Demise

			COATING - ARATHANE 5753]								
43	Spacer 4-40 2mm length	16	Ultem® (polyetherimide)	Cylinder	0.5592	4.76	2	0.5592	No	-	Demise
44	Spacer 4-40 2mm length	16	Ultem® (polyetherimide)	Cylinder	0.5592	4.76	2	0.5592	No	-	Demise
45	Thin Hex Nut, M3 Thread, 18-8 Stainless Steel	6	18-8 Stainless Steel	Cylinder	1.74096	6.35	1.8	1.74096	No	-	Demise
46	PEM Nut, 18-8 Stainless Steel	1	18-8 Stainless Steel	Cylinder	0.4731	6.35	2.78	0.4731	No	-	Demise
47	Plunger 1a.9	1	Accura® Bluestone™	Cylinder	0.33952	5.4	23.63	0.33952	No	-	Demise
48	Plunger 2	1	Accura® Bluestone™	Cylinder	0.65	5	22.5	0.65	No	-	Demise
49	Plunger 1b	1	Accura® Bluestone™	Cylinder	0.40053	5.4	25	0.40053	No	-	Demise
50	Deployment Switch	2	PCT Polyester/Aluminum/ Silver	Box	16.18792	24.8	37.8	16.18792	No		Demise
51	Deployment Switch - Short	1	PCT Polyester/Aluminum/ Silver	Box	6.90082	23.2	37.8	6.90082	No	-	Demise
52	Flat Head Machine Screw, M3 Thread, A2 Stainless Steel, 14 mm length	6	A2 Stainless Steel	Cylinder	4.1541	3	14	4.1541	Yes	2500°	0 km
53	Sparkfun SunnyBuddy	1	PCB: FR4, Copper, Plastic [CONFORMAL COATING - ARATHANE 5753]	Board	18.652438	31	47	18.652438	No	-	Demise
54	Hex Nut, 4-40, 316 Stainless Steel	4	316 Stainless Steel	Cylinder	1.5994	1.8	7.34	1.5994	Yes	2500°	Demise
55	Flat Head Screw, 4-40, 316 Stainless Steel, 5_16 inch length	4	316 Stainless Steel	Cylinder	1.45188	1.42	7.95	1.45188	Yes	2500°	Demise
56	Battery 3.7V 2000mAh	2	LiFePO4; Aluminum foil (JIS A8079,A8021)	Box	83.33676	51	62.5	83.33676	No	-	Demise
57	Bus Bar	2	Copper	Box	3	13	25	3	No	-	Demise
58	18 AWG Wire	36	Copper, Teflon insulation	Cylinder	29.52	1.03	110	29.52	No	-°	Demise
59	Copper Wire	3	Copper	Cylinder	0.45	0.127	1257	0.45	No	-	Demise
60	Magnetorquer	3	MuMetal (nickel-iron alloy)	Cylinder	31.32717	6.35	37.3	31.32717	No	2649°	0 km

61	Magnetoquer Mount	3	Accura® Bluestone™	Box	4.1341 8	8.5	15	4.13418	No	-	Demise
62	M2_14mm 18-8 SS Phillips Flat Head Screw	4	18-8 Stainless Steel	Cylinder	0.1439 2	2	14	0.14392	Yes	2500°	Demise
63	M2_12mm Metric 18-8 SS Flat Head Phil Machine Screw	5	18-8 Stainless Steel	Cylinder	0.1561	2	12	0.1561	Yes	2500°	Demise
64	Floor Plate	1	Accura® Bluestone™	Plate	18.5	73	75	18.5	No	-	Demise
65	TTL Sensor	1	PCB: FR4, Copper, Plastic [CONFORMAL COATING - ARATHANE 5753]	Board	3.8602 4	20	28	3.86024	No	-	Demise
66	Mini Photocell	1	PCB: FR4, Copper, Plastic [CONFORMAL COATING - ARATHANE 5753]	Cylinder	0.3664 832	4.5	2.4	0.36648 32	No	-	Demise
67	M3 12 mm Metric 18-8SS Flat Head Phillips	2	18-8 Stainless Steel	Cylinder	0.1502	3	12	0.1502	Yes	2500°	0 km
68	M3 14mm Metric Flat Head Phillips	4	18-8 Stainless Steel	Cylinder	0.3478 8	3	14	0.34788	Yes	2500°	0 km
69	M3 14mm Metric Flat Head Phillips	4	18-8 Stainless Steel	Cylinder	0.3478 8	3	14	0.34788	Yes	2500°	Demise
70	M3 nut Type 18-8 SS Thin Hex Nut	6	18-8 Stainless Steel	Cylinder	0.2176 2	6.3	1.3	0.21762	Yes	2500°	Demise
71	M2 nut_type 18-8 SS Thin Hex Nut - DIN 439B	6	18-8 Stainless Steel	Cylinder	0.0808 2	4.6	0.84	0.08082	Yes	2500°	Demise
72	Mass Ballast 1	2	Lead	Box	5.02	2.85	40	5.02	No	-	Demise
73	Mass Ballast 2 (in Holder)	3	Lead	Box	3.21	5	13	3.21	No	-	Demise
74	Mass Ballast 3 (Main)	1	Lead	Box	11.08	12	56	11.08	No	-	Demise
75	M2_12mm Metric 18-8 SS Flat Head Phil Machine Screw	2	18-8 Stainless Steel	Cylinder	0.0624 4	2	12	0.06244	Yes	2500°	Demise
76	Light Sail	1	Polycarbonate Film	Plate	151	740	740	151	No	-	Demise
77	Nitinol Wire	2	Nitinol SEA light oxide wire	Cylinder	9.8	0.737	1000	9.8	No	-	Demise
78	ChipSat "Monarch"	4	PCB: Kapton, Copper, Plastic [CONFORMAL COATING - ARATHANE 5753]	Board	59.84	50	50	59.84	No	-	Demise

79	Secondary locking mechanism for screws	N/A	LOCTITE® 222MS™	N/A	Negligi ble	N/A	N/A	Negligib le	No	-	Demise