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

Signature Page

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Reply to Attn of: VA-H1

November 14, 2018

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 RFTSat

REFERENCES:

A. *NASA Procedural Requirements for Limiting Orbital Debris Generation*, NPR 8715.6A, 5 February 2008
B. *Process for Limiting Orbital Debris*, NASA-STD-8719.14A, 25 May 2012
C. International Space Station Reference Trajectory, delivered May 2017
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. 4th ed. Northbrook, IL, Underwriters Laboratories, 2007
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. HQ OSMA Email:6U CubeSat Battery Non Passivation Suzanne Aleman to Justin Treptow, 8 August 2017

The intent of this report is to satisfy the orbital debris requirements listed in ref. (a) for RFTSat, a CubeSat which will be launching on a Falcon 9 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.

RECORD OF REVISIONS		
REV	**DESCRIPTION**	**DATE**
0	Original submission	Nov 2018

The following table summarizes the compliance status of the RFTSat CubeSat to be flown on the Falcon 9 vehicle. RFTSat 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 3.7years
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 RFTSat

Section 1: Program Management and Mission Overview

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

RFTSat: Dr. Joshua Griffin, Principal Investigator, Northwest Nazarene University

Program Milestone Schedule	
Task	**Date**
CubeSat Selection	February 17th, 2017
Mission Readiness Review	January 26th, 2019
Dispenser Integration	February 26th, 2019
Delivery to SEOPS	March 5th, 2019
Launch	May 7th, 2019

Figure 1: Program Milestone Schedule

The RFTSat CubeSat will be launched as a payload on a Falcon 9 launch vehicle executing the SpX-18 cargo mission for the International Space Station. The RFTSat CubeSat will then be deployed at a to-be-determined later date by a Cygnus vehicle departing the International Space Station.

The current launch date is projected to be May 7th, 2019

Section 2: Spacecraft Description

Table 2: ~~Table 2: RFTSat~~ outlines its generic attributes.

Table 2: RFTSat

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

The following pages further describe RFTSat.

RFTSat – Northwest Nazarene University – 3U

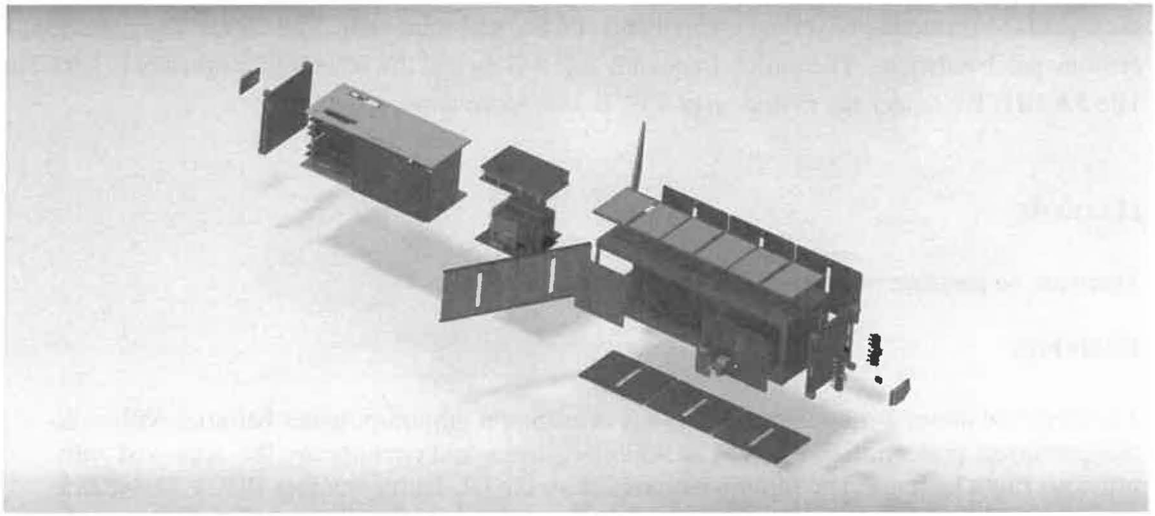

Figure 2: RFTSat Exploded View

Overview

The goal of the Radio Frequency Tag Satellite (RFTSat) mission is to develop and demonstrate the first space-based 5.8GHz RF backscattering communications system. It will allow a wireless passive RF tag to harvest RF energy transmitted through space from an RF reader on the spacecraft, store that energy in a supercapacitor, and power an MCU and various sensors on the tag. Then the collected sensor data will be transmitted back to the reader by modulating this information on the backscattered RF signal. This tag will be mounted at the end of an unfurling carbon fiber boom and will be used to measure accelerations, temperature, and radiation TID at a distance of about 1 m from the reader. All data will be downlinked to earth via GlobalStar satellite network.

CONOPS

Upon deployment, RFTSat will power up and start a 50 minute countdown timer. At 50 minutes, the GlobalStar radio will activate and send health beacon data every 90 minutes. During the first week of operation, the attitude control (magnets and mu-metal) system will detumble the spacecraft. During weeks 2 and 3 of the mission, the deployables will deploy from the sides of the craft, allowing the carbon fiber boom and RF tag to incrementally deploy to 0.6 meters away from the spacecraft, where the boom then locks into place. During this time, RF tag data will be measured at each increment. From week 4 to the end of the mission, the frequency of measurement and GlobalStar transmission to earth will be reduced by 90%, in addition to continuing health beacons every 90 minutes.

Materials

The RFTSat structure is made of Aluminum 6061-T6 and contains standard commercial-off-the-shelf (COTS) materials, electrical components, PCBs, and solar cells. The GlobalStar radio uses 3 ceramic patch antennas. The uplink frequency is 2.4 GHz and the downlink frequency is 1.6 GHz. The 5.8 GHz RF reader/tag system uses 4 PCB microstrip antennas.

Hazards

There are no pressure vessels, hazardous or exotic materials.

Batteries

The electrical power storage system consists of common lithium-polymer batteries with over-charge/current protection circuitry. The lithium batteries and circuitry are ISS approved with previous flight heritage. The lithium batteries carry the UL-listing number BBCV.MH48285.

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.

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 RFTSat, 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 the RFTSat 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 prevents a catastrophic failure, so that passivation at EOM is not necessary to prevent an explosion or deflagration large enough to release orbital debris.

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4 shows that with a maximum CubeSat lifetime of 3.7 years maximum, the RFTSat 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.

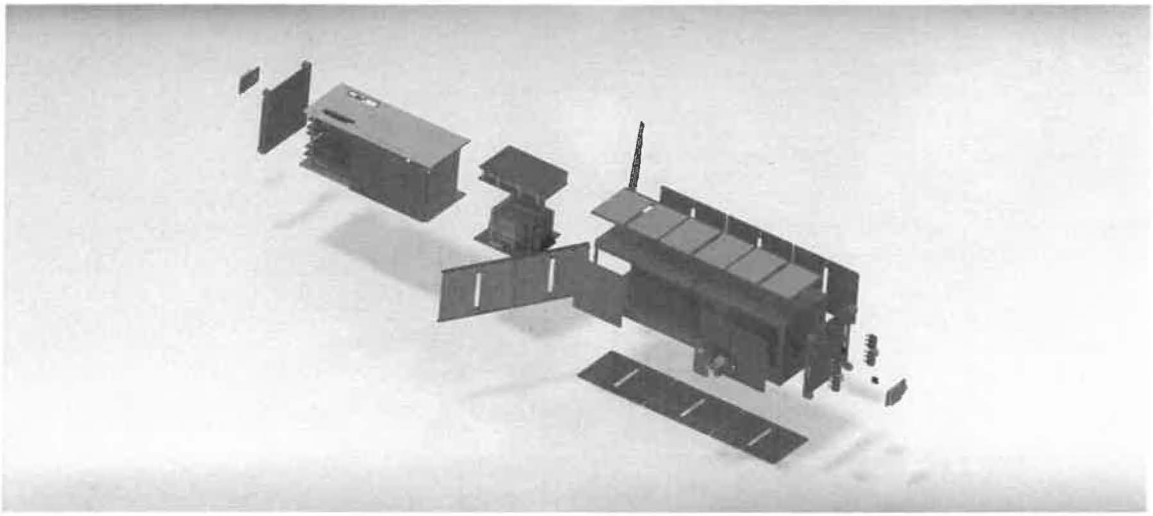

Figure 4: RFTSat Expanded View (with solar panels deployed)

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

Equation 1: Mean Cross Sectional Area for Convex Objects

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

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~~Equation 1~~. This configuration renders the longest orbital life times for all CubeSat.

Once a CubeSat has been ejected from the CubeSat dispenser and deployables have been extended, Equation 2~~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

The projected orbit altitude is projected to be either 450 km or 500 km, so both of these altitudes were evaluated. Also, both of these altitudes were evaluated at both solar panel stowed and solar panel deployed cross sectional areas.
With an area to mass ratio of 0.0098 m^2/kg, DAS yields 3.7 years for orbit lifetime for its stowed state at a 500 km orbit altitude, and 2.7 years of orbit lifetime at a 450 km orbit

for its stowed state. The RFTSat CubeSat was calculated to have a probability of collision of 0.0 at these altitudes for these respective orbital lifetimes. Table 3 provides complete results of these scenarios.

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.

RFTSat		500 nm orbit	450 nm orbit
	Mass (kg)	2.8	2.8
Stowed	Mean C/S Area (m^2)	0.027	0.027
Stowed	Area-to Mass (m^2/kg)	0.0098	0.0098
Stowed	**Orbital Lifetime (years)**	**3.707**	**2.683**
Stowed	**Probability of collision (10^X)**	**0.0000**	**0.0000**
Deployed	Mean C/S Area (m^2)	0.045	0.045
Deployed	Area-to Mass (m^2/kg)	0.0163	0.0163
Deployed	**Orbital Lifetime (years)**	**3.034**	**2.267**
Deployed	**Probability of collision (10^X)**	**0.000**	**0.000**

Solar Flux Table Dated 3/29/2018

Table 3: CubeSat Orbital Lifetime & Collision Probability

The probability of RFTSat 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.

The CubeSat manifested on this mission have no capability nor have plans for end-of-mission disposal, therefore requirement 4.5-2 is not applicable.

Assessment of spacecraft compliance with Requirements 4.5-1 shows RFTSat to be compliant. Requirement 4.5-2 is not applicable to this mission.

Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

RFTSat 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 RFTSat in its stowed configuration at a 500 km orbital altitude 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

$$\frac{0.027\ m^2}{2.75\ kg} = 0.098\frac{m^2}{kg}$$

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: 5100 km maximum apogee 500 km maximum perigee altitudes with an inclination of 51.6° at deployment no earlier than April 2018. An area to mass ratio of ~**0.0981** m^2/kg for the RFTSat CubeSat was used. DAS 2.1.1 yields a 3.7 year orbital lifetime for RFTSat in its stowed state at a 500 km orbital altitude.

This meets requirement 4.6-1.

Section 7: Assessment of Spacecraft Reentry Hazards

A detailed reentry assessment of the RFTSat components 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 they reenter the atmosphere, further reducing the risk that they pose.

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: RFTSat High Melting Temperature Material Analysis

Name	Material	Total Mass (kg)	Demise Alt (km)	Kinetic Energy (J)
Diagnostic Connectors	Stainless Steel	.008	0	1
Spring Plungers	Stainless Steel	.0006	77.4	N/A
Payload Mounting Screw	Stainless Steel	.0024	77.6	N/A
Capacitors	Tantalum	.001	77.6	N/A
Screws	Stainless Steel	.002	77.9	N/A
3/8 screws	Stainless Steel	.019	77.6	N/A
1/4 screws	Stainless Steel	.019	77.8	N/A
1/8 screws	Stainless Steel	.005	77.8	N/A
3/16 screws	Stainless Steel	.002	77.8	N/A
¼ 30-80 screw	Stainless Steel	.0004	77.8	N/A

The majority of stainless steel components demise upon reentry and RFTSat 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 RFTSat

Name	Status	Risk of Human Casualty
RFTSat	Compliant	0.00000

*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 RFTSat has a 1:0 probability as none of its components have more than 15J of energy.

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

Section 8: Assessment for Tether Missions

RFTSat will not be deploying any tethers.

RFTSat 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
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cc: VA-H/Mr. Carney
VA-H1/Mr. Beaver
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SA-D2/Mr. Frattin
SA-D2/Mr. Hale
SA-D2/Mr. Henry
Analex-3/Mr. Davis
Analex-22/Ms. Ramos

Appendix Index:

Appendix A. RFTSat 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	Chassis	1	Alumimium 6061	Box	764.5	100.0	340.5	100	No	-	Demise
2	(+)Z Endplate	1	Alumimium 6061	Square	32.9	100	100	1	No	-	Demise
3	-Z Endplate	1	Alumimium 6061	Square	61.1	100	100	1	No	-	Demise
4	Access Panel	4	Alumimium 6061	Square	141.2	100	100	1	No	-	Demise
3	Patch Antennas	3	Ceramic	Square	31.2	25.0	25.0	4.5	No	-	Demise
4	Horizon Sensors	2	Fiberglass/Plastic	Square	4.8	25.3	32.0	2	No	-	Demise
5	Diagnostic Connectors	2	Stainless/Brass/Plastic	Rectangle	8.8	13.8	19.9	7.8	Yes	2500°	0 km
6	RF Tag Board Door	1	FR4 Multilayer PCB/Rogers	Square	100.0	83.0	124.6	4.4	No	-	Demise
7	RF Tag Board Door Gasket	1	Viton	Square Ring	1.0	83.0	121.5	1.6	No	-	Demise
8	RF Reader Antenna Board	1	Rogers RO4730	Square	15.0	90.8	80.0	1.6	No	-	Demise
9	Solar Panels	13	Fiberglass/GaAs	Square	198.9	80.0	100.0	2	No	-	Demise
10	Large Inhibit Switch	4	Steel / Plastic		4.8	10.2	20.0	6.5	No	-	Demise
11	Rail End Inhibit Switch	2	Steel / Plastic		0.6	10.2	20.0	6.5	No	-	Demise
12	Spring Plungers	2	Steel / Stainless Steel	Round	0.6	3.5	15.0		Yes	2500°	Demise
13	Ballast	1	Aluminium 6061	Block	55.0	97.6	79.8	1.58	No	-	Demise
14	Payload Mounting Screw	8	Stainless Steel	Cylinder	2.4	10.7	4.2		Yes	2500°	Demise
15	Mu Metal	6	Nickel	Rectangle	13.2	10.0	100.0	10	No	-	Demise
16	Magnet	3	Neodymium	Box	4.5	15	2	2	No	-	Demise
17	EPS/Battery/Radio	1	FR4 Multilayer PCB/Lithium Polymer/Brass/Teflon /Steel/Kapton	Box	268.7	83.65	87	48.7	No	-	Demise
18	Extra Battery	1	Lithium Polymer	Box	224.7	70	100	20.18	No	-	Demise
19	PLL Board	1	FR4 Multilayer PCB/Rogers 4003C	Square	40	80	80	2	No	-	Demise

20	DSP Board	1	FR4 Multilayer PCB	Square	40	80	80	2	No	-	Demise
21	Amp Board	1	FR4 Multilayer PCB	Square	40	80	80	2	No	-	Demise
22	Motor Board	1	FR4 Multilayer PCB	Square	40	80	80	2	No	-	Demise
23	IB Board	1	FR4 Multilayer PCB	Square	40	80	80	2	No	-	Demise
24	Temp Board	1	FR4 Multilayer PCB	Square	40	80	80	2	No	-	Demise
25	Lower Slider	1	Aluminium 6061	Rectangle	149	201	88	4	No	-	Demise
26	Upper Slider	1	Aluminium 6061	Rectangle	140	201	88	4	No	-	Demise
27	PLL Mount	1	Delrin	Block	50	90	90	7	No	-	Demise
28	Capacitors	5	Tantalum	Square	1	2	2	2	Yes	5463°	Demise
29	Boom Box	1	Aluminium/Carbon Fiber/Stainless	Box	200	63	83	36	No	-	Demise
30	Elastic Hinge	8	Nitinol Flatwire	Cylinder	0.8	2	3		No	-	Demise
31	Burn Wire	1	Nylon			-	-	-	No	-	Demise
32	Standoffs	50	Aluminium 6061	Cylinder	1	4	-	-	No	-	Demise
33	Screws	20	Stainless Steel	Cylinder	2	2	-	-	Yes	2500°	Demise
34	3/8" #2-56 Screw	2	Stainless Steel	Cylinder	0.6	-	-	-	Yes	2500°	Demise
35	1/4" #2-56 Screw	82	Stainless Steel	Cylinder	18.9	-	-	-	Yes	2500°	Demise
36	1/8" #2-56 Screw	34	Stainless Steel	Cylinder	5.1	-	-	-	Yes	2500°	Demise
37	3/16" #2-56 Screw	12	Stainless Steel	Cylinder	2.3	-	-	-	Yes	2500°	Demise
38	1/4" 30-80 Screw	4	Stainless Steel	Cylinder	0.4	-	-	-	Yes	2500°	Demise
39	1/16" #2 Spacer	36	Aluminium	Cylinder	0.7	-	-	-	No	-	Demise
40	Potting		Silicone	-	5	-	-	-	No	-	Demise
41	LocTite		Methacrylate	-	2	-	-	-	No	-	Demise
42	Staking Compound		3M Scotch Weld 2216	-	-	-	-	-	No	-	Demise
43	Cabling	2 feet	Copper Alloy	-	-	-	-	-	No	-	Demise
44	Heat Shrink		FP-301 Polyolefin	-	-	-	-	-	No	-	Demise
45	Thermal Pad	1	Black Carbon/Polysiloxan	Square	-	192	288	2.5	No	-	Demise