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November 7, 2019

Orbital Debris Assessment for the PR-CuNaR2 CubeSat per NASA-STD 8719.14A

Signature Page

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Reply to Attn of: VA-H1

November 7, 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 PR-CuNaR2

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, 4 25 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.
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 PR-CuNaR2 Cubesat, which will be part of the ELaNa-31 complement, launching on the SpaceX-21 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 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	October 2019

Section 1: Program Management and Mission Overview

The PR-CuNaR2 CubeSat is sponsored by the Human Exploration and Operations Mission Directorate at NASA Headquarters. The Program Executive is Anne Sweet. Responsible program/project manager and senior scientific and management personnel are as follows:

PR-CuNaR2: Dr. Amilcar Rincon-Charris, Inter American University of Puerto Rico – Bayamon Campus

The following table summarizes the compliance status of the PR-CuNaR2 CubeSat to be flown on the SpaceX-21 launch vehicle and deployed from the International Space Station. PR-CuNaR2 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 ~1.015 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	January 2018
Delivery to Nanoracks	June 1st, 2020
Launch	August 5th, 2020

Figure 1: Program Milestone Schedule

The PR-CuNaR2 CubeSat will be launched as a payload as part of the ELaNa-31 complement. ELaNa-31 will be launched on the SpaceX Falcon 9 launch vehicle executing the SpX-21 mission.. The current launch date is NET August 5th, 2020.

PR-CuNaR2 weighs approximately 2.7 kg.

Section 2: Spacecraft Description

Table 2 outlines the generic attributes of the spacecraft.

Table 2: PR-CuNaR2

CubeSat Names	CubeSat Quantity	CubeSat size (mm^3)	CubeSat Masses (kg)
PR-CuNaR2	1	333.5 x 107.3 107.3	2.66

The following pages describe PR-CuNaR2.

PR-CuNaR2– Inter American University of Puerto Rico, Bayamon Campus – 3U

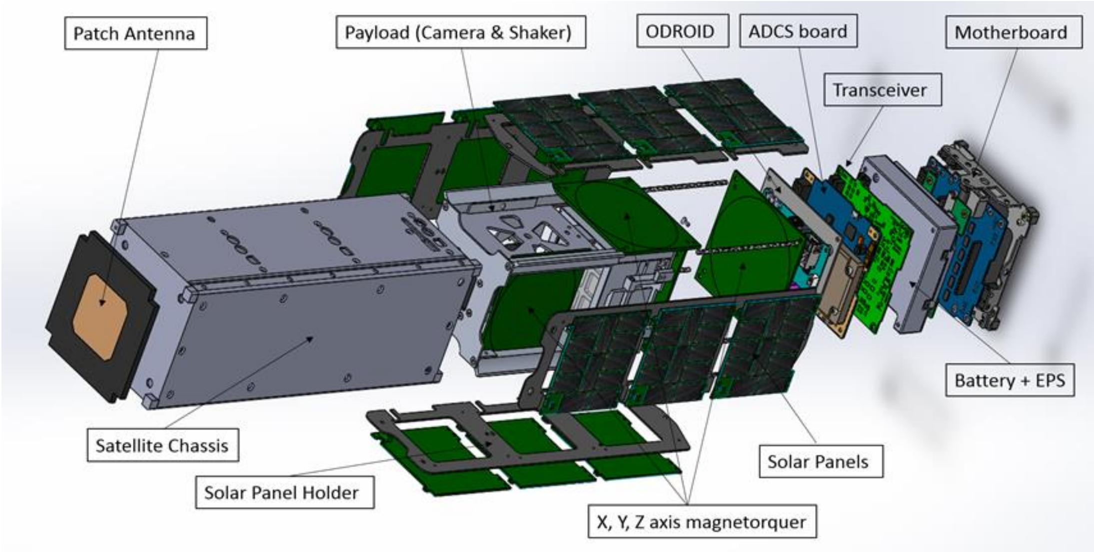

Figure 2: PR-CuNaR2 Exploded View

Overview

The PR-CuNaR2 (Puerto Rico CubeSat NanoRocks-2) is a 3U CubeSat scientific investigation by the Inter American University of Puerto Rico, Bayamon, to increase understanding of the outcomes of relevant collisions among millimeter-sized particles, or "pebbles", in a protoplanetary disk. The experiment will take advantage of the long duration and high quality of microgravity provided by a CubeSat in Low-Earth-Orbit (LEO) to obtain a large sample of collisional outcomes at very low velocities (<10 cm/s). The experiment consists of chambers containing different populations of particles that are mechanically shaken to induce collisions between the particles. Video of the collisions will indicate the collision parameters (mass, density and composition of particles, and collision velocities) that lead to sticking, rebound, and fragmentation of aggregates. In the case of rebounds, the coefficient of restitution (a measure of the dissipation of energy) will be measured.

CONOPS

Upon deployment from the dispenser, PR-CuNaR2 starts counting down a 30 minutes timer and then will power up the Motherboard. Next, the IMU begins to measure the position and the passive control system begins to actuate. After stabilizing the CubeSat, the camera board, the backlight and the solenoids are turned on for 10 seconds. The program of the camera is executed for 5 minutes and then proceeds to store the video and process it to be sent by radio. The CubeSat enters charging mode. Approximately 4 days following deployment, payload tests will begin and continue for the on orbit lifetime of the spacecraft, approximately 1 year. The radio will be powered on in receive mode only. As the satellite flies over a ground station, the station will continuously beacon towards the satellite. When the satellite radio hears the beacon, along with the proper serial number code, it will respond, and a link will be established. At that point, the ground station will ask the satellite for information, typically payload data or onboard telemetry. The satellite will respond by downlinking the requested information. When the link is lost due to the satellite passing out of view and the satellite was transmitting, the satellite will try up to 3 seconds to complete the last packet transmitted. The satellite will then revert to a passive receive mode and wait for the next beacon from a ground station.

Materials

Much of this satellite is composed of 6061-O, 6061-T4, 6061-T6 aluminum, Delrin and PCB materials. There is glass in the payload, and it is made from quartz. The radio uses a ceramic patch antenna.

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.

Section 3: Assessment of Spacecraft Debris Released during Normal Operations

The assessment of spacecraft debris requires the identification of any object (>1 mm) expected to be released from the spacecraft any time after launch, including object dimensions, mass, and material.

The section 3 requires rationale/necessity for release of each object, time of release of each object, relative to launch time, release velocity of each object with respect to spacecraft, expected orbital parameters (apogee, perigee, and inclination) of each object after release, calculated orbital lifetime of each object, including time spent in Low Earth Orbit (LEO), and an assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2.

No releases are planned for PR-CuNaR2, 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 PR-CuNaR2.

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 1.015 years maximum, PR-CuNaR2 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.

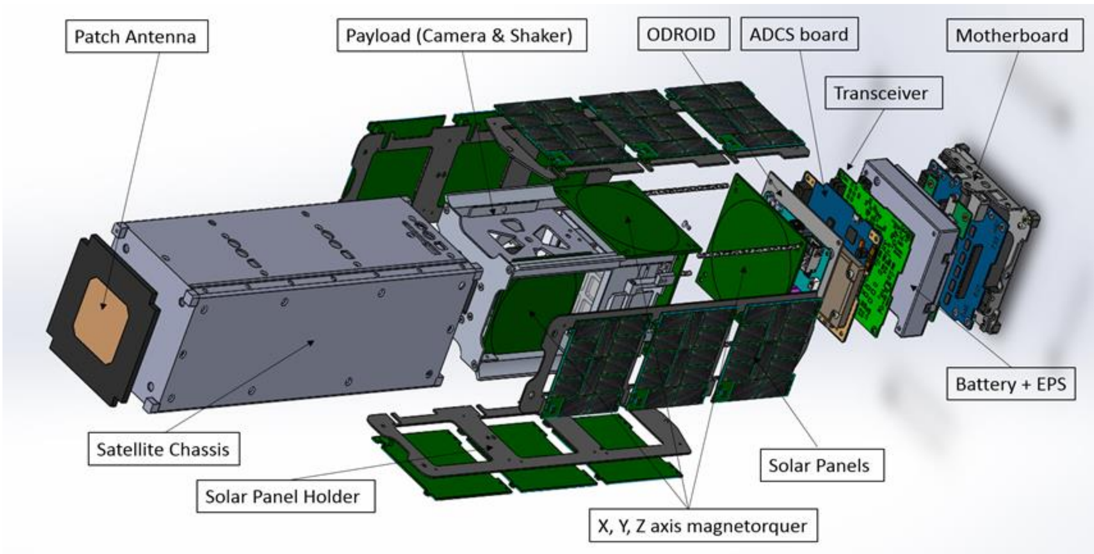

Figure 4: PR-CuNar2 Expanded View

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

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 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.

PR-CuNaR2 orbit at deployment has a 427 km apogee with a 412 km perigee. With an area to mass ratio of 0.0111 m^2/kg, DAS yields ~1.1 years for orbit lifetime for its as deployed state, which in turn is used to obtain the collision probability. PR-CuNar2 is calculated to have a probability of collision of 0.0. Table 3 below provides complete results.

There will be no post-mission disposal operation. As such the identification of all systems and components required to accomplish post-mission disposal operation, including passivation and maneuvering, is not applicable.

	CubeSat	PR-CuNar2
	Mass (kg)	2.66
As deployed	**Mean C/S Area (m^2)**	0.0294
	Area-to Mass (m^2/kg)	0.01106
	Orbital Lifetime (yrs)	**1.02**
	Probability of collision (10^X)	**0.0000**

Solar Flux Table Dated 9/24/2019

Table 3: CubeSat Orbital Lifetime & Collision Probability

The probability of PR-CuNaR2 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.

PR-CuNaR2 has no capability nor has plans for end-of-mission disposal, therefore requirement 4.5-2 is not applicable.

Assessment of spacecraft compliance with Requirements 4.5-1 shows PR-CuNaR2 to be compliant.

PR-CuNaR2 has no capability or plans for end-of-mission disposal, therefore Requirement 4.5-2 is not applicable. PR-CuNaR2 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

PR-CUNAR2 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.

The area-to-mass for PR-CuNaR2 is calculated for is as follows:

$$\frac{\boldsymbol{Mean}\ {}^{\boldsymbol{C}}\!/\!_{\boldsymbol{S}}\,\boldsymbol{Area}\ (\boldsymbol{m^2})}{\boldsymbol{Mass}\ (\boldsymbol{kg})} = \boldsymbol{Area-to-Mass}\ \left(\frac{\boldsymbol{m^2}}{\boldsymbol{kg}}\right)$$

Equation 3: Area to Mass

$$\frac{0.0294\ m^2}{2.657\ kg} = \ 0.011\frac{m^2}{kg}$$

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 November 2020. An area to mass ratio of ~0.011m^2/kg for the PR-CuNaR2 CubeSat was used. DAS 2.1.1 yields a ~1.0 years orbit lifetime for PR-CuNaR2 in its deployed 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 PR-CuNaR2 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: PR-CuNaR2 High Melting Temperature Material Analysis

Name	Material	Total Mass (kg)	Demise Alt (km)	Kinetic Energy (J)
music wire springs	Steel	.0002	77.8	-
torsion springs	Steel	.0002	77.6	-
Flat head 2.5 mm x10	18-8 Stainless Steel	.00039	77.8	-
Button head 3 mm x 6	18-8 Stainless Steel	.00039	76.9	-
press in nuts 2.5mm - 3mm	18-8 Stainless Steel	.00030	77.3	-
flat head 3mm x 20	18-8 Stainless Steel	.0015.	77.7	-
flat head 3mm x 6	18-8 Stainless Steel	.00039	77.8	-
socket head 4/40 x 1" 3/8 in	18-8 Stainless Steel	.00179	77.8	-
nuts 2.5mm	18-8 Stainless Steel	.00022	77.8	-
4/40 nuts in	18-8 Stainless Steel	.00022	78.0	-
Solenoids	Steel	.010	75.9	-
Magnet	AlNiCo	.011	0	0
Hysteresis material	HyMu80	.013	0	2

The majority of stainless steel components demise upon reentry and PR-CuNaR2 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
PR-CuNaR2	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 PR-CuNaR2 has a 1:0 probability, as none of their components have more than 15J of energy.

PR-CuNaR2 is shown to be in compliance with Requirement 4.7-1 of NASA-STD-8719.14A.

Section 8: Assessment for Tether Missions

PR-CuNaR2 will not be deploying any tethers.

PR-CuNaR2 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
SA-D2/Mr. Frattin
SA-D2/Mr. Hale
SA-D2/Mr. Henry
Analex-3/Mr. Davis
Analex-22/Ms. Ramos

Appendix Index:

Appendix A. PR-CuNaR2 Component List

]	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter / Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (F°)	Survivability
1	**PR-CuNaR2 2 - 3U**		6061 aluminum	Box	2657 g	107.3 mm	333.5 mm	107.3 mm	**No**	-	Demise
2	3U Chassis	1	6061 aluminum	Box	550.4	100 mm	333.5 mm	100 mm	**No**	-	Demise
3	Solar Panels	12	Fiber glass	plates	376.8	82.2 mm	88.7 mm	1.58 mm	**No**	-	Demise
4	Patch antenna	1	Ceramic, copper,aluminum and brass	Plates	15	50.8mm	50.8mm	6.35mm	**No**	-	Demise
5	Rails	3	6061 aluminum	Rectangle	119.70	12.5 mm	188.4 mm	12.5 mm	**No**	-	Demise
6	rails special corner	1	6061 aluminum	Rectangle	38.80	11 mm	188.4 mm	12.5 mm	**No**	-	Demise
7	Base v2	1	6061 aluminum	Box	67.10	87.7 mm	3 mm	87.7 mm	**No**	-	Demise
8	Arm	2	Delrin	Rectangle	6.74	6.8 mm	46 mm	18.8 mm	**No**	-	Demise
9	support Arm 1	2	6061 aluminum	Rectangle	7.72	8.67 mm	37 mm	20 mm	**No**	-	Demise
10	support Arm 2	2	6061 aluminum	Rectangle	7.72	7 mm	37 mm	20 mm	**No**	-	Demise
11	Solenoid holder vertical	1	6061 aluminum	Box	6.19	26.3 mm	16.5 mm	22 mm	**No**	-	Demise
12	Solenoid holder horizontal	2	6061 aluminum	Box	12.34	16 mm	16 mm	28.2 mm	**No**	-	Demise
13	payload stopper	4	Delrin	L plate	3.76	8 mm	10.7 mm	10.7 mm	**No**	-	Demise
14	Z stopper	2	Delrin	L plate	2.52	6.5 mm	19.6 mm	20 mm	**No**	-	Demise
15	X,Y stopper	1	Delrin	L plate	4.34	44.9 mm	35.5 mm	24 mm	**No**	-	Demise
16	Plate 1	1	aluminum sheet	sheets	32.10	87.9 mm	120 mm	1.6 mm	**No**	-	Demise
17	plate 2	1	aluminum sheet	sheets	32.10	87.9 mm	120 mm	1.6 mm	**No**	-	Demise
18	plate 3	1	aluminum sheet	sheets	32.10	87.9 mm	120 mm	1.6 mm	**No**	-	Demise
19	camera mount (full block)	1	6061 aluminum	Box	18.40	45 mm	32.5 mm	45 mm	**No**	-	Demise
20	camera plate	1	6061 aluminum	Plate	29.10	87.7 mm	2 mm	87.7 mm	**No**	-	Demise
21	payload bottom	1	6061 aluminum	Box	87.00	65 mm	28 mm	65 mm	**No**	-	Demise

22	clamp 1	2	6061 aluminum	L shape	28.00	7 mm	33.3 mm	65 mm	**No**	-	Demise
23	clamp 2	2	6061 aluminum	L shape	25.80	7 mm	33.3 mm	69 mm	**No**	-	Demise
24	glass	2	quartz glass	plate	59.00	65 mm	3 mm	65 mm	**No**	-	Demise
25	diffuser	1	PTFE	sheet	5.30	65 mm	1 mm	65 mm	**No**	-	Demise
26	divider	1	6061 aluminum	rectangle	21.10	65 mm	4 mm	65 mm	**No**	-	Demise
27	music wire springs	4	steel	cylindrical	0.80	4.8 mm	24.6 mm	4.8 mm	Yes	2600°F	Demise
28	torsion springs	2	steel	wire	0.40	2mm	1mm	-	Yes	2600°F	Demise
29	Flat head 2.5 mm x10	36	18-8 Stainless Steel	cylindrical	14.04	2.5 mm	10 mm	2.5 mm	Yes	2600°F	Demise
30	Button head 3 mm x 6	12	18-8 Stainless Steel	cylindrical	4.68	3 mm	6 mm	3 mm	Yes	2600°F	Demise
31	flat head 4/40 x 1/4 in	4	aluminum	cylindrical	0.56	2.54 mm	6.35 mm	2.54 mm	No	-	Demise
32	press in nuts 2.5mm - 3mm	6	18-8 stainless steel	cylindrical	1.80	2.5 mm	2 mm	2.5 mm	Yes	2600°F	Demise
33	flat head 3mm x 20	2	18-8 stainless steel	cylindrical	3.00	3 mm	20 mm	3 mm	Yes	2600°F	Demise
34	flat head 3mm x 6	8	18-8 stainless steel	cylindrical	3.12	3 mm	6 mm	3 mm	Yes	2600°F	Demise
35	socket head 4/40 x 1" 3/8 in	2	18-8 stainless steel	cylindrical	3.58	2.54 mm	34.9 mm	2.54 mm	Yes	2600°F	Demise
36	nuts 2.5mm	28	18-8 stainless steel	cylindrical	6.16	3 mm	2 mm	3 mm	Yes	2600°F	Demise
37	4/40 nuts in	2	18-8 stainless steel	cylindrical	0.44	3.2 mm	2 mm	3.2 mm	Yes	2600°F	Demise
38	Motherboard (MB) Rev:D	1	FR4 Standar - Ceramic, copper,aluminum and brass	rectangle	88	96mm	90mm	1.6mm	No	-	Demise
39	Pluggable Processor Module (PPM) D2	1	FR4 Standar - Ceramic, copper,aluminum and brass	rectangle	17	54.6mm	89.5mm	1.6mm	No	-	Demise
40	ADCS Board	1	FR4 Standar - Ceramic, copper,aluminum and brass	rectangle	90	96mm	90mm	1.6mm	No	-	Demise
41	IMU	1	FR4 Standar - Ceramic, copper,aluminum and brass	Box	48	44.25mm	47.25mm	14.25mm	No	-	Demise
42	Comm Board	1	FR4 Standar - Ceramic,	rectangle	85	96mm	90mm	1.6mm	No	-	Demise

			copper,aluminum and brass								
43	Micro computer	1	FR4 Standar - Ceramic, copper,aluminum and brass	Box	50	83mm	59mm	18mm	No	-	Demise
44	Camera	1	FR4 Standar - Ceramic, copper,aluminum and brass	Box	36	29mm	29mm	30mm	No	-	Demise
45	LEDs Board	1	FR4 Standar - Ceramic, copper,aluminum and brass	rectangle	5	24mm	24mm	1.6mm	No	-	Demise
46	Solenoids	3	steel	Cylidrical	30	5mm	10mm	-	No	-	Demise
47	EPS & Battery	1	Ceramic, copper,aluminum and brass	Box	350	90mm	95.9mm	30mm	No	-	Demise
48	Magnet	1	Alnico5	Cylindrical	11	6.4mm	35.6mm		Yes	1470°F	0 km
49	Hysteresis Material	2	HyMu 80	Rectangle	26	1.588mm	70mm		Yes	2650°F	0 km