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Orbital Debris Assessment for
The D3 CubeSat
per NASA-STD 8719.14A

Signature Page

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Reply to Attn of: VA-H1

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 D3 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 December 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. Debris Assessment Software User's Guide: Version 3.0.1, NASA/TP-2019-220300

The intent of this report is to satisfy the orbital debris requirements listed in ref. (a) for the D3 CubeSat launching on the SpX-24 mission, performing a Commercial Resupply Mission (CRS) to the International Space Station. 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 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	November 2020

Section 1: Program Management and Mission Overview

D3 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:

Camilio Riano, Project Manager, University of Florida

The following table summarizes the compliance status of D3, which will be flown on the SpX-24 Commercial Resupply (CRS) mission to the International Space Station. D3 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 1.889 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	Compliant	CubeSat will deorbit passively if boom deployment fails/malfunctions
4.6-5	Compliant	
4.7-1	Compliant	Non-credible risk of human casualty
4.8-1	Compliant	No planned tether releases

D3 will be launched as a payload on the SpX-24 CRS mission to the International Space Station. The current launch date is November 1, 2021.

Section 2: Spacecraft Description

Table 1 outlines its generic attributes.

Table 2: D3 Attributes

CubeSat Names	CubeSat Quantity	CubeSat size (mm^3)	CubeSat Mass (kg)
D3	1	227 x 100 x 100	2.64

The following pages describe the D3 CubeSat.

D3 – University of Florida – 2U

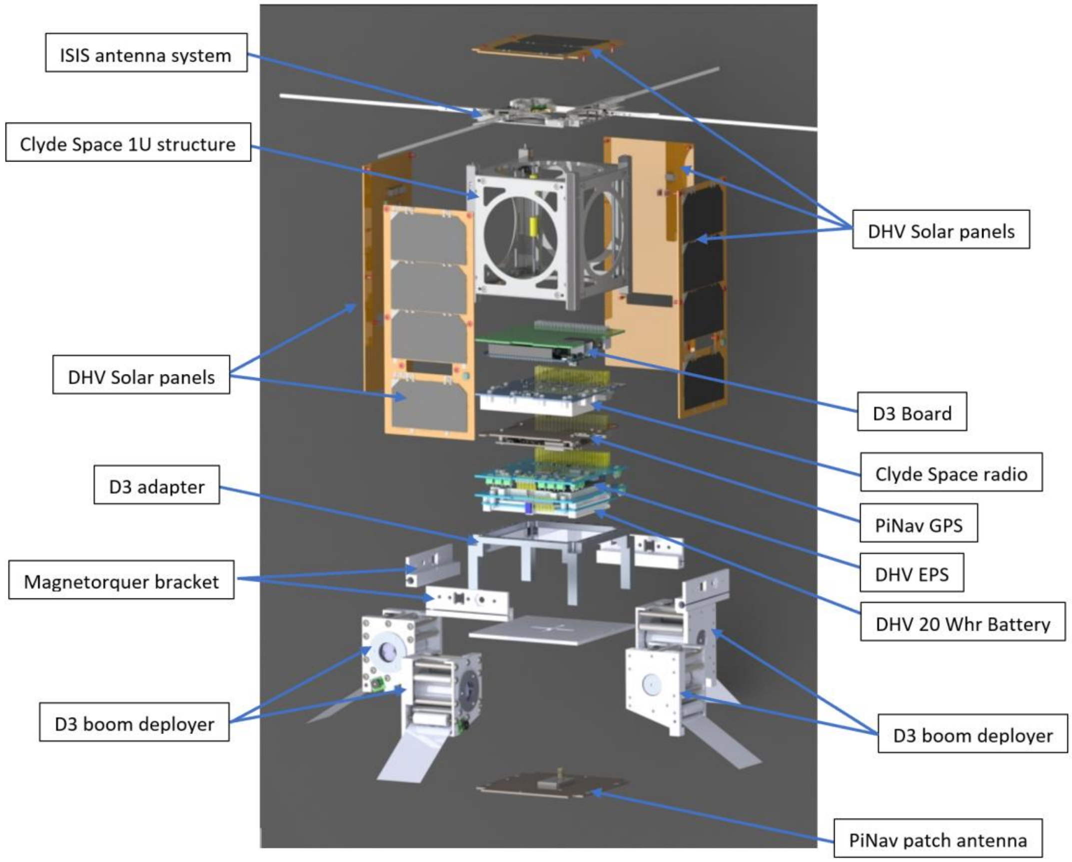

Figure 2: D2 Exploded View

Overview

The D3 CubeSat is designed to test the D3 device, which enables a standard CubeSat for using the drag acceleration for orbital maneuvering. The mission will test a de-orbit point targeting algorithm developed at the University of Florida ADvanced Autonomous Multiple Spacecraft (ADAMUS) laboratory.

CONOPS

Once the CubeSat is deployed from the dispenser it will power up and start collecting solar power. The CubeSat will wait for 30 minutes to start collecting telemetry data. Once the batteries are sufficiently charged, antennas will be deployed and the CubeSat's UHF beacon transmission is enabled. Once communication is established and checkouts are performed, the CubeSat will send telemetry on request and receive commands. A magnetorquer-based de-tumbling law starts until angular rotation rates are below a pre-defined threshold. After the de-tumbling maneuver, the D3 booms are deployed at a pre-defined level for passive attitude stabilization and increase of orbital decay. Once a pre-defined threshold of remaining longitude controllability is reached, the de-orbit algorithm starts generating guidance profiles which are uploaded to the CubeSat. Upon reception of a guidance profile, the CubeSat starts tracking it by modulating the D3 booms. Guidance updates are periodically uplinked to the CubeSat based on its real location. The CubeSat keeps tracking the guidance until the desired re-entry location is reached.

Materials

The D3 1U structure made of Aluminum 6082-T6, and a D3 adapter and D3 Base plate made of Aluminum 6061-T6, all the D3 device screws and the D3 booms are made of austenitic 316 stainless steel and the electronic boards contain Commercial off the shelf Materials.

Hazards

D3 does not have any pressurized vessels or hazardous materials.

Batteries

D3 has a commercially available power system with 20W-hr lithium-ion battery pack and overcharge and overcurrent protection. The batteries are UL recognized components according to UL1642 and IEC 62133 ed. 2 certified.

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 D3 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 D3.

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 CubeSat 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 1.889 years maximum, D3 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.

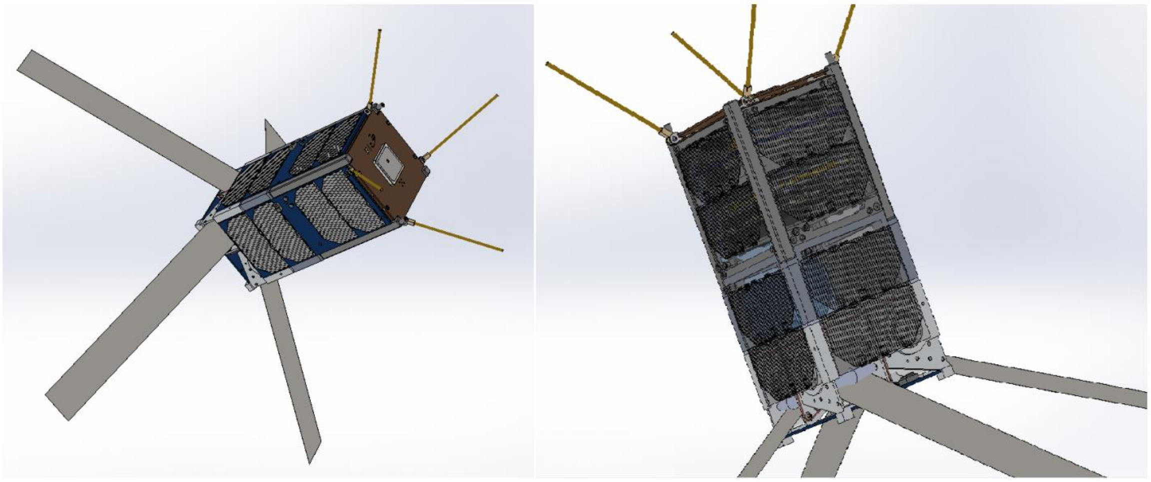

Figure 4: D3 Deployed View

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

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. This configuration renders the longest orbital life times for all CubeSats.

Once a CubeSat is 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

D3 expected orbit at deployment has a 426.7 apogee and a 410.5 km perigee at a xx° inclination. With an area to mass ratio of 0.0808 m^2/kg, DAS yields 1.889 years for orbit lifetime for its as-deployed state, which in turn is used to obtain the collision probability. D3 is calculated to have a probability of collision of 0.0. Table 3 below provides complete results.

CubeSat		D3
	Mass (kg)	2.64
Stowed	Mean C/S Area (m^2)	0.0214
	Area-to Mass (m^2/kg)	0.0808
	Orbital Lifetime (yrs)	**1.889**
	Probability of collision (10^X)	**0.0000**
Booms Fully Extended	Mean C/S Area (m^2)	0.3237
	Area-to Mass (m^2/kg)	0.1223
	Orbital Lifetime (yrs)	**0.219**
	Probability of collision (10^X)	**0.0000**

Solar Flux Table Dated 9/29/2020

Table 2: CubeSat Orbital Lifetime & Collision Probability

The probability of D3 colliding with debris and meteoroids greater than 10 cm in diameter and capable of preventing post-mission disposal is less than 0.00000, for any configuration. This satisfies the 0.001 maximum probability requirement 4.5-1.

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

This ODAR also serves as the EOMP (End of Mission Plan)

Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

During it's mission, D3 will test a system of booms that is used to control the rate at which the CubeSat's orbit will decay. Even if this system completely fails, the D3 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 will be achieved via passive atmospheric reentry even if the deorbit device does not deploy.

Calculating the area-to-mass ratio for the worst-case (smallest Area-to-Mass) post-mission disposal finds D3 in its as-ejected configuration as the worst case. The area-to-mass is calculated for is as follows:

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

Equation 3: Area to Mass

$$\frac{0.021\ m^2}{2.64\ kg} = \ 0.008\frac{m^2}{kg}$$

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

<u>DAS Orbital Lifetime Calculations:</u>
DAS inputs are: 426.7 km maximum apogee 410.5 km maximum perigee altitudes with an inclination of 51.6º at deployment no earlier than October 2021. An area to mass ratio of 0.008 m^2/kg for the D3 CubeSat is used. DAS yields a 1.89 years orbit lifetime for D3 in its as-deployed state.

This meets requirement 4.6-1. For the complete list of CubeSat orbital lifetimes reference **Table 2: 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 D3 was performed. The assessment used DAS, a conservative tool used by the NASA Orbital Debris Office to verify Requirement 4.7-1. The analysis is intended to provide a bounding analysis for characterizing the survivability of a CubeSat's component during re-entry. For example, when DAS shows a component surviving reentry, it is not taking into account the material ablating away or charring due to oxidative heating. Both physical effects are experienced upon reentry and will decrease the mass and size of the real-life components as the reenter the atmosphere, reducing the risk they pose still further.

The following steps are used to identify and evaluate a components potential reentry risk relative to the 4.7-1 requirement of having less than 15 J of kinetic energy and a 1:10,000 probability of a human casualty in the event the survive reentry.

1. Low melting temperature (less than 1000 °C) components are identified as materials that would never survive reentry and pose no risk to human casualty. This is confirmed through DAS analysis that showed materials with melting temperatures equal to or below that of copper (1080 °C) will always demise upon reentry for any size component up to the dimensions of a 1U CubeSat.

2. The remaining high temperature materials are shown to pose negligible risk to human casualty through a bounding DAS analysis of the highest temperature components, stainless steel (1500°C). If a component is of similar dimensions and has a melting temperature between 1000 °C and 1500°C, it can be expected to possess the same negligible risk as stainless steel components.

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

Table 4: D3 High Melting Temperature Material Analysis

Name	Material	Total Mass (kg)	Demise Alt (km)	Kinetic Energy (J)
spacers	Steel 316	.042	76.8	-
Boom encoders	Steel 316	.005	77.2	-
Boom motors	Steel (generic)	.520	74.2	-
Motor gearheads	Steel (generic)	.088	74.0	-
Booms	steel	.360	0	.89

The majority of high melting point components demise upon reentry and D3 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
D3	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 D3 has a 1:0 probability, as none of its components have more than 15J of energy.

D3 is compliant with Requirement 4.7-1 of NASA-STD-8719.14A.

Section 8: Assessment for Tether Missions

D3 will not be deploying any tethers.

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-E2/Mr. Cheney
AIS2/Mrs. Pariso
SA-D2/Mr. Frattin
SA-D2/Mr. Hale
SA-D2/Mr. Henry
Analex-3/Mr. Davis
Analex-22/Ms. Ramos

Appendix Index:

Appendix A. D3 Component List

Item Number	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter / Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (Fº)	Survivability
1	D3 CubeSat (2U)		-	Box	2640.62	100	100	227	-	-	Demise
2	1U Structure, ClydeSpace	1	Al 6082-T6	Box	154.3	100	100	113.5	-	-	Demise
3	D3 Adapter	1	6061-T6/Black Hardcoat Anodize	Box	49.1	100	100	42.5	-	-	Demise
4	ISIS ANTS.DS.001 antenna system	1	PCB	Plate	83.7	100	100	7.3	-	-	Demise
5	Skyfox piNAV GPS	1	PCB+Pin header	Plate	82.2	95.89	90.17	14.6	-	-	Demise
6	Clyde Space radio CPUT UTRX	1	PCB+Pin header	Plate	96.1	95.89	90.17	14.59	-	-	Demise
7	DHV EPS	1	PCB+Pin header	Plate	72	95.89	90.17	12.32	-	-	Demise
8	DHV Battery	1	PCB+Pin header	Plate	190	95.89	90.17	20.1	-	-	Demise
9	Skyfox piNAV Patch Antenna	1	PCB	Plate	51.2	100.0	100.0	4.0	-	-	Demise
10	D3 board	1	PCB+Pin header	Plate	98	95.89	90.17	18.0	-	-	Demise
11	DHV 2U solar panels	4	PCB+SolAero ZTJ Solar cells	Plate	210.8	80.6	6.36	1815.8	-	-	Demise
12	DHV 1U solar panel	1	PCB+SolAero ZTJ Solar cells	Plate	31.4	98	98	5.9	-	-	Demise
13	D3 BasePlate	1	6061-T6/Black Hardcoat Anodize	Plate	76.9	100	100	2	-	-	Demise
14	Long Rollers in Deployer	24	PTFE	Cylinder	16.08	6.5	-	40	-	-	Demise
15	"Watermelon" Roller	4	PTFE	Cylinder	17	6.5	-	30	-	-	Demise
16	Short Roller in Deployer	4	Urethane	Cylinder	3.92	90	-	13	-	-	Demise
17	D3 Male Shell	4	6061-T6 Aluminum	Plate	117.6	10.5	49	68	-	-	Demise
18	D3 Female Shell	4	6061-T6 Aluminum	Plate	53.2	8.5	48	61.5	-	-	Demise
19	Drum to hold Boom	4	6061-T6 Aluminum	Cylinder	86.76	24	-	44	-	-	Demise
20	D3 Sleeve	4	6061-T6 Aluminum	Cylinder	33.24	34	-	42.5	-	-	Demise
21	D3 Deployer Spacers	16	AISI 316 Annealed Steel	Cylinder	42.24	4.5	-	42	Yes	2500°	Demise

22	Encoder Shaft in Deployer	4	AISI 316 Annealed Steel	Cylinder	4.76	2.0	-	51.0	Yes	2500°	Demise
23	D3 Deployer	4	6061-T6/Black Hardcoat Anodize	Box	322.4	48	48	61.5	-	-	Demise
24	D3 Booms	4	316 Austenitic Stainless Steel + Insta-blak SS-370	rolled shim stock	360	40	3700	0.0762	Yes	2500°	0 km
25	D3 motors	4	Steel, black coated (housing)+NdFeB(Magnet)+	cylinder	52	15	-	23.9	Yes	2500°	Demise
26	D3 motor gearheads	4	steel	cylinder	88	16	-	54.6	Yes	2500°	Demise
27	Magnetorquer brackets (long)	4	6061-T6/Black Hardcoat Anodize	box	84.76	75	10	24	-	-	Demise
28	Magnetorquer brackets (short)	2	6061-T6/Black Hardcoat Anodize	box	24.38	67	10	10	-	-	Demise
29	Magnetorquer coil	1	Copper - Enamel wire	wire	101	0.45	-	100000	-	-	Demise
30	screws for solar panels	28	316 Stainless steel	Cylinder	7.28	2	-	6		-	Demise
31	Ribbon cable	1	Valor DR-48+Ribbon (Belden)	plate	8.9	78	2.54	88.9	-	-	Demise
32	Data Harness solar panels	41	ESCC 3901 024 01 wire - fluopolymer PTFE	wire	15.4	0.32	-	200	-	-	Demise
33	Data Harness antenna system	9	A28000-009 wire - Liquid crystal polymer LCP	wire	6	0.25	-	457	-	-	Demise
34	M3 x 0.5mm Button Head x 50mm	44	Passivate 18-8 SS	Cylinder	14.26	-	-	-	Yes	2500°	Demise
35	M2 x 0.4mm Flat Head x 4mm	12	316 SS	Cylinder	1.18	-	-	-	Yes	2500°	Demise
36	M3 x 0.5mm Set Screw x 8mm	4	316 SS	Cylinder	1.34	-	-	-	Yes	2500°	Demise
37	M2 x 0.4mm Flat Head x 6mm	16	18-8 SS	Cylinder	2.58	-	-	-	Yes	2500°	Demise
38	M3 x 0.5mm Button Head x 18mm	4	Passivate 18-8 SS	Cylinder	0.41	-	-	-	Yes	2500°	Demise