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

Signature Page

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Reply to Attn of: VA-H1

TO: Liam Cheney, LSP Mission Manager, NASA/KSC/VA-C

FROM: Jimmy Smith, NASA/KSC/VA-H1

SUBJECT: Orbital Debris Assessment Report (ODAR) for the BeaverCube II 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-8719.14C, 5 November 2021
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 3.1, NASA/TP-2019-220300

The intent of this report is to satisfy the orbital debris requirements listed in ref. (a) for the BeaverCube II CubeSat launching on SpX-27. 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	05/16/2022

Section 1: Program Management and Mission Overview

BeaverCube II is sponsored by the Space Operations Mission Directorate at NASA Headquarters. The Program Executive is Sam Johnson. Responsible program/project manager and senior scientific and management personnel are as follows:

Dr. Kerri Cahoy, PI, Massachusetts Institute of Technology

The following table summarizes the compliance status of BeaverCube II, which will be flown on the SpX-27 mission to the International Space Station. The current launch date is planned for 02/19/2023. DAS version 3.2.1 was used to generate the data provided in this document. BeaverCube II 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 0.964 years
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

Section 2: Spacecraft Description

Table 2 outlines its generic attributes.

Table 2: BeaverCube II Attributes

CubeSat Names	CubeSat Quantity	CubeSat size (mm)	CubeSat Mass (kg)
BeaverCube II	1	340 x 100 x 100	3.94

The following pages describe the BeaverCube II CubeSat.

BeaverCube II – Massachusetts Institute of Technology – 3U

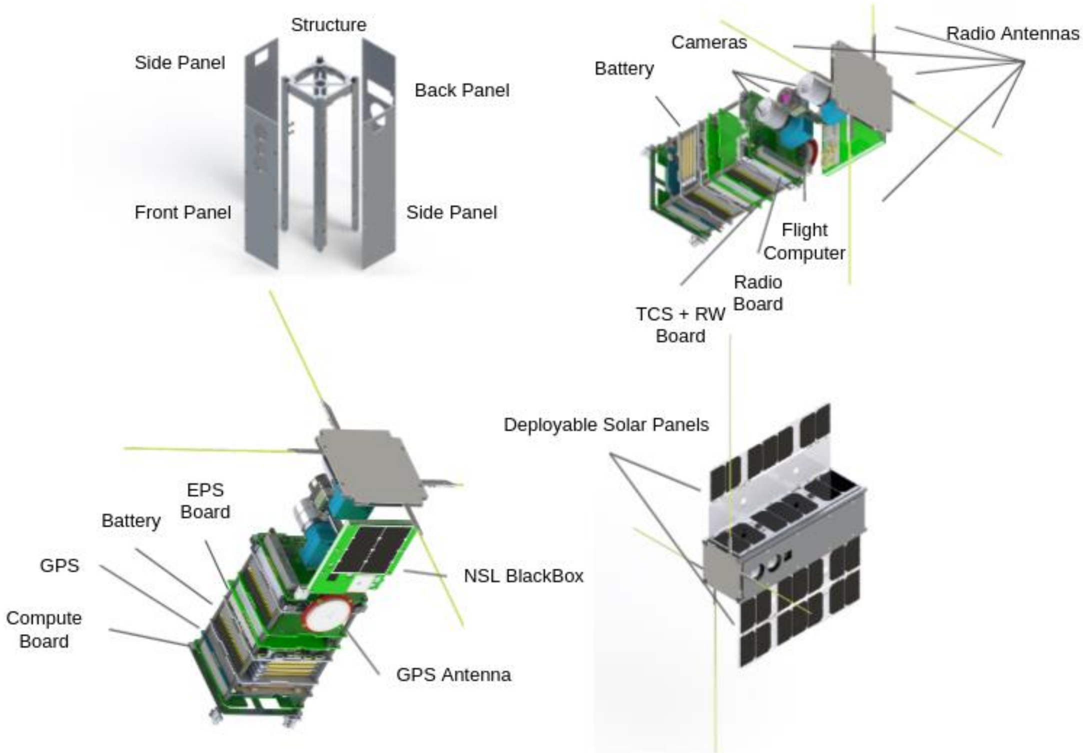

Figure 1: BeaverCube II Expanded View

Overview

BeaverCube II will demonstrate the use of a Compute Board to accelerate modern AI algorithms to perform autonomous task management and image processing to expand the mission capabilities of an Earth Observing CubeSat. BeaverCube II will be studying oceanographic regions of interest, focusing on ocean fronts, using a LWIR camera and two visible spectrum cameras, one configured with a filter to measure the 443nm band for chlorophyll-a concentration and the other in a standard RGB configuration.

CONOPS

Upon deployment from the CubeSat dispenser, BeaverCube II will power on and wait 60 minutes before deploying its antennas and solar panels. It will then activate it's UHF beacon. The first few passes will see ground operators perform checkouts of the spacecraft before attempting to transition to mission operations. Mission operations will involve uplinking command script to perform imaging passes and commanding dummy runs of the autonomous algorithms to validate their performance. Once the autonomous algorithms have been validated in a dummy configuration, operations will begin testing the autonomous operation of the satellite by only uplinking targets of interest and letting the satellite compute its own command scripts.

Materials

The CubeSat structure is made of Aluminum 6061-T6. It contains all standard commercial off the shelf (COTS) materials, electrical components, PCBs and solar cells. The UHF radio antenna elements are made of a NiTi-alloy based shape memory alloy.

Hazards

There are no pressure vessels, hazardous, or exotic materials.

Batteries

The electrical power system consists of all Cyde Space components, using 2 3U Double-Deployed Photon Solar Panels, the Starbuck Nano PDU, and the 40wH Optimus lithium-ion polymer battery. This battery utilizes the VARTA LPP 503759 lithium-ion battery cells which carry the UL-listing number BBCV2.MH13654.

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 on the BeaverCube II 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 II.

As discussed in Reference H, with respect to 3U and smaller CubeSats, 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.

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 0.964 years maximum, BeaverCube II 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.

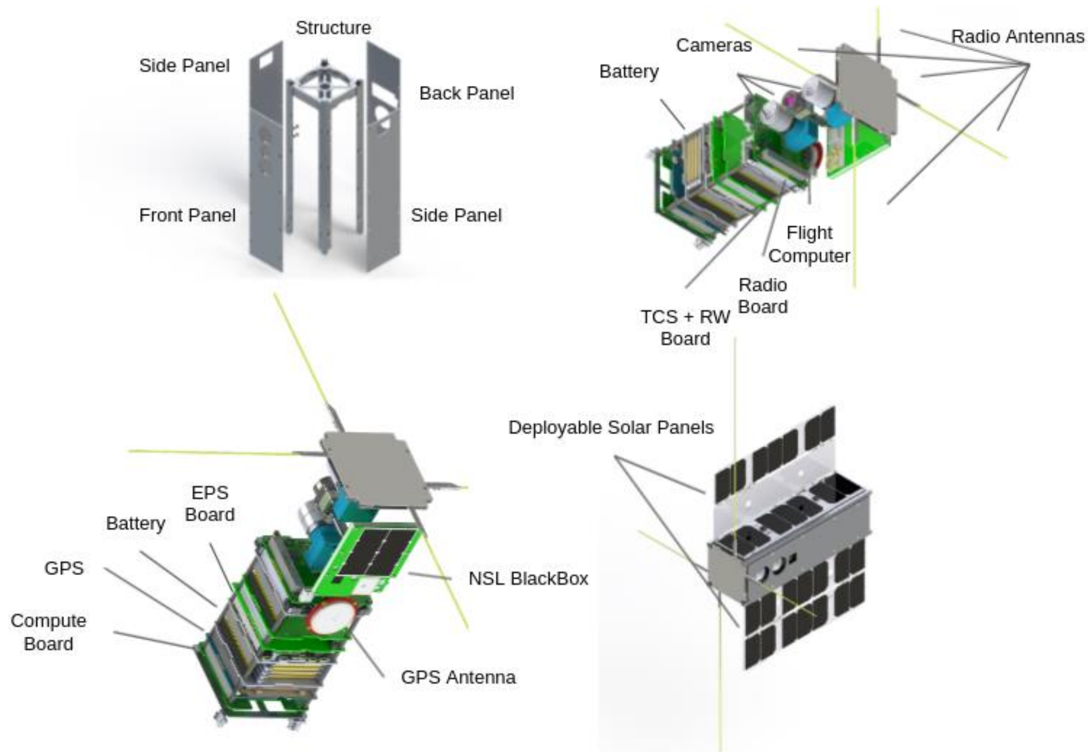

Figure 2: BeaverCube II Deployed View

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

Equation 1: Mean Cross Sectional Area for Convex Objects

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

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 $\boldsymbol{Mean\ CSA} = \frac{\sum \boldsymbol{Surface\ Area}}{\mathbf{4}} = \frac{\mathbf{2}*[(\boldsymbol{w}*\boldsymbol{l})+(\boldsymbol{w}*\boldsymbol{h})+(\boldsymbol{l}*\boldsymbol{h})]}{\mathbf{4}}$ Equation 1. This configuration renders the longest orbital life times for all CubeSats.

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 II's expected orbit at deployment has a 424.2-km apogee and a 408.3-km perigee at a 51.6° inclination. With an area to mass ratio of 0.0099 m^2/kg, DAS yields 0.964 years for orbit lifetime for its as-ejected state, which in turn is used to obtain the collision probability. BeaverCube II is calculated to have a probability of collision of 0.0. Table 3 below provides complete results.

	CubeSat	BeaverCube II
	Mass (kg)	3.94
As-Ejected	Mean C/S Area (m^2)	0.0390
As-Ejected	Area-to Mass (m^2/kg)	0.0099
As-Ejected	Orbital Lifetime (yrs)	**0.964**
As-Ejected	Probability of collision	**4.15E-08**
Deployed	Mean C/S Area (m^2)	0.0690
Deployed	Area-to Mass (m^2/kg)	0.0175
Deployed	Orbital Lifetime (yrs)	**0.783**
Deployed	Probability of collision	**4.98E-08**

Solar Flux Table Dated 03/30/2022

Table 3: CubeSat Orbital Lifetime & Collision Probability

The probability of BeaverCube II colliding with debris or meteoroids greater than 10 cm in diameter that are 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 II to be compliant.

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

Section 6: Assessment of Spacecraft Post-Mission Disposal Plans and Procedures

BeaverCube II 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 BeaverCube II in its stowed configuration as the worst case. The area-to-mass is calculated 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

$$\frac{0.0390\ m^2}{3.94\ kg} = 0.0099\,\frac{m^2}{kg}$$

The assessment of the spacecraft illustrates it is compliant with Requirements 4.6-1 through 4.6-5.

<u>DAS Orbital Lifetime Calculations:</u>
DAS inputs are: 424.2-km maximum apogee and 408.3-km maximum perigee altitudes with an inclination of 51.6º at deployment no earlier than 02/19/2023. An area to mass ratio of ~0.0099 m^2/kg for the BeaverCube II CubeSat was used. DAS yields a 0.964 years orbit lifetime for BeaverCube II in its as-ejected state.

This meets requirement 4.6-1.

Section 7: Assessment of Spacecraft Reentry Hazards

A detailed assessment of the components to be flown on BeaverCube II 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 they reenter the atmosphere, reducing the risk they pose still further.

The following steps are used to identify and evaluate a component's 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 it survives reentry.

1. Low melting temperature (less than 1000 °C) components are identified as materials that would never survive reentry and pose no risk of 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 of human casualty through a bounding DAS analysis of the highest temperature components, stainless steel (1500°C). If a component has a melting temperature between 1000 °C and 1500°C, it can be expected to possess the same negligible risk as a stainless steel component of similar dimensions.

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 Program Office (Reference I)

Table 4: BeaverCube II High Melting Temperature Material Analysis

Name	Material	Total Mass (kg)	Demise Alt (km)	Kinetic Energy (J)
Patch Antenna	Ceramic	0.016	0.0	1.56
RTD	Platinum	0.010	72.2	0.00

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

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

Section 8: Assessment for Tether Missions

BeaverCube II 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 launch provider.

If you have any questions, please contact the undersigned at jimmy.d.smith@nasa.gov.

/original signed by/

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Flight Design Analyst
NASA/KSC/VA-H1

cc: VA-C/Liam J. Cheney
VA-C/Norman L. Phelps
AIS2/ Jennifer A. Snyder
SA-D1/Kevin R. Villa
SA-D2/Homero Hidalgo

Appendix Index:

Appendix A. BeaverCube II Component List

Appendix A. BeaverCube II 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 II 3U	1	AL 7075-T6	Box	3936.6	100	340	100	N	N/A	
2	CubeSat Structure	1	Al 7075-T6	Box	818.00	100	340	100	N	N/A	
3	**GlobalStar Radio (Components Below)**	**1**	--	**Box**		**82**	**100**	**11.1**	N	N/A	
4	Frame	1	Aluminum 6061	Box	6.5	82	100	7	N	N/A	
5	Patch Antenna	2	Ceramic	Box	8	25	25	6	Y	7224.8	1.56 J
6	Top Solar PCB	1	FR4	Flat Slab	19	82	100	1	N	N/A	
7	Batteries	1	Lithium Ion	Box	15	15	34	41	N	N/A	
8	Main PCB	1	FR4	Flat Slab	60	82	100	1	N	N/A	
9	Fasteners (#2-56)	7	SS18-8	Cylinder	0.3	5	9	N/A	N	N/A	
10	Deployable Antenna	1	PCB substrate, NiTi-alloy SMA antenna, aluminum housing	Box	85.00	98	98	5.9	N	N/A	
11	OpenLST Radio	1	FR4 PCB	Flat Slab	14	50	60	11.3	N	N/A	
12	NovaTel GPS	1	FR4 PCB	Box	31	46	71	11	N	N/A	
13	GPS Antenna	1	Aluminum	Cylinder	120	143	N/A	30	N	N/A	
14	Clyde Space Starbuck-Nano EPS	1	Aluminum	Box	86	90.17	95.89	16.2	N	N/A	
15	Clyde Space Optimus-40 Battery	1	Lithium Polymer	Box	335	90.17	95.89	27.35	N	N/A	
16	3U Double-Deployed Solar Panel	2	PCB substrate, Kapton overlay	Flat slab	330	100	300	N/A	N	N/A	
17	i-MTQ ADCS Board	1	FR4	Box	196	90	95	24	N	N/A	

18	CubeWheel Small Plus	1	Aluminum housing, AluCoat 650, FR4	Box	90	33.4	33.4	31.5	N	N/A	
19	FLIR Boson Imaging Camera w/ Lens	1	Vanadium Oxide Sensor, Aluminum Housing		41	21	21	11	N	N/A	
20	VIS Camera	2	Aluminum housing	Box	80	39.8	39.8	16.5	N	N/A	
21	Tamron M118FM16 Megapixel Fixed-focal Industrial Lens (16mm) (Lens for Visible Camera)	1	Aluminum housing	Cylinder	39	29	N/A	24	N	N/A	
22	Raspberry Pi Compute 3 Lite (CM3L)	2	PCB Substrate	Flat Slab	12	30	67.6	3.7	N	N/A	
23	C&DH Board	1	FR4	Flat Slab	160	90	96	1.6	N	N/A	
24	Compute Board	1	FR4	Flat Slab	160	90	96	1.6	N	N/A	
25	Compute Board Heat Sink	1	Aluminum	Box	200	90	96	8.57	N	N/A	
26	RTD	5	Platinum on alumina substrate, ceramic case, Teflon case	Box	2	4.8	8.0	2.0	Y	3215.0	0.00 J
27	Heater	3	Kapton	Flat Slab	31	19.1	63.5	0.2	N	N/A	
28	Thermal Control Board	1	FR4	Box	96	90.0	96.0	1.6	N	N/A	
29	Fasteners	100	18-8 SS	Cylinder	2.5	4.5	6.5	N/A	N	N/A	
30	Connectors	30	Copper Alloy, PTFE	Cable	5	Various	N/A	N/A	N	N/A	