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Orbital Debris Assessment for
The CUTE 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 CUTE Mission

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
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 the CUTE CubeSat launching on the Atlas V launch vehicle, as part of the Landsat-9 mission. 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 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	January 2020

Section 1: Program Management and Mission Overview

The CUTE 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 CUTE mission to be flown on the LandSat-9 mission. CUTE 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 ~11 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	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	November 5, 2019
Delivery to USAF	NET November 30, 2020
Launch	January 14, 2021

Figure 1: Program Milestone Schedule

CUTE will be launched as a secondary payload on the Atlas V launch vehicle executing the Landsat-9 mission. The current launch date is currently projected to be January 14, 2021 (U/R).

CUTE has total mass of about 10.7 kg.

Section 2: Spacecraft Description

CUTE is flying as part of the ELaNa-34 mission complement. Table 2 outlines its generic attributes.

Table 2: CUTE Attributes

CubeSat Names	CubeSat Quantity	CubeSat size (mm^3)	CubeSat Masses (kg)
CUTE	1	362 x 237 x 110	10.65

The following pages describe the CUTE CubeSat.

CUTE – LASP/University of Colorado – 6U

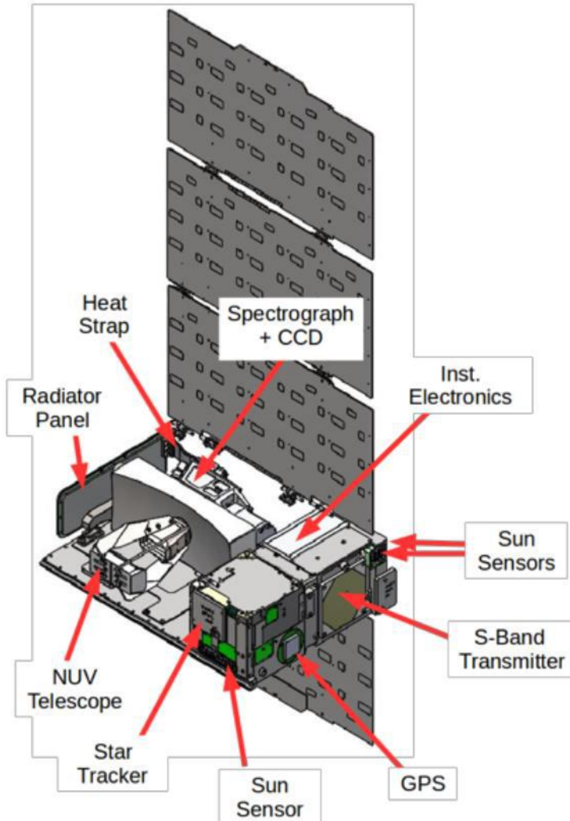

Figure 2: CUTE Deployed view

Overview

The Colorado Ultraviolet Transit Experiment (CUTE) is a 6U CubeSat mission developed by the University of Colorado at Boulder and the Laboratory for Atmospheric and Space Physics (LASP) (Figure 1). It is designed to characterize the interaction between the atmospheres of close-orbiting exoplanets and their host stars via near-ultraviolet (NUV) transit spectroscopy. CUTE is expected to launch into a 550 km circular Sun-synchronous orbit (SSO) with a 3-year mission lifetime. The mission's ground segment, including mission operations (S-band 2402 MHz; UHF-band 437.25 MHz) science and engineering data processing, and data distribution are located at LASP in Boulder, Colorado.

CONOPS

Upon deployment from the dispenser, the solar arrays and will deploy and start counting down timers. At 30 minutes, spacecraft will power on and begin UHF beaconing. For the first few passes the ground station operators will attempt UHF communications to perform checkouts of the spacecraft. Following state-of-health verification, S-band download link will be established and science payload alignment and verification phase will commence. Approximately 14 days from launch, initial science observations will begin and full science testing will execute. Approximately 30 days from launch, nominal science and calibration observations will commence and continue for at least 2 years.

Materials

The CubeSat structure is made of Aluminum (6061-T6), with an anodized finish. It contains all standard commercial off the shelf (COTS) materials, electrical components, PCBs and solar cells. The S-band radio uses a ceramic patch antenna. The largest individual item in the system is the telescope primary mirror, which is made of ZEODUR™. The optical assembly also contains small invar and titanium components, which are listed in the attached ODAR spreadsheet (with dimensions and CAD drawings).

The optical system, photon sensor, and spacecraft components have been staked prior to final testing and delivery. The CUTE team has long experience with low-outgassing epoxies and bonding agents to prevent contamination of the optical system and other spacecraft. CUTE employs 3M 2216 structural epoxy, Arathane 5753 parts A & B for detector electric cooling system bonding, and Arathane 5750 for conformal coating of payload electronic boards.

Hazards

There are no hazardous or exotic materials.

Batteries

The CUTE XB1 has an internal lithium ion battery pack (18650; 6ASM2840 XB1 6 cell battery pack SN 029; UL listing BBCV2.MH19896, tested to UL level 1642) made up of 3 series cells and 2 parallel strings with a capacity of 6.8 A-h and a maximum voltage of 12.9 V.

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 CUTE 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 CUTE.

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 lifetime of approximately 11 years maximum, CUTE 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: CUTE Exploded and assembled views

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

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 is stowed in a convex configuration, indicating there are no elements of the CubeSat obscuring another element of the CubeSat from view. Thus, the mean CSA for the stowed CubeSat was calculated using Equation 1. This configuration renders the longest orbital life time.

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

CUTE's expected (10.7 kg) orbit at deployment is 550 km circular at an ~97.598° inclination. With an area to mass ratio of .006476 m^2/kg, DAS yields ~11 years for orbit lifetime for its stowed state, which in turn is used to obtain the collision probability. The

CUTE 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		CUTE
	Mass (kg)	10.65
Stowed	Mean C/S Area (m^2)	0.068967
	Area-to Mass (m^2/kg)	0.006476
	Orbital Lifetime (yrs)	**10.98**
	Probability of collision (10^X)	**0.0000**
Deployed	Mean C/S Area (m^2)	0.2240
	Area-to Mass (m^2/kg)	0.02103
	Orbital Lifetime (yrs)	**2.11**
	Probability of collision (10^X)	**0.0000**

Solar Flux Table Dated 9/24/2019

Table 3: CubeSat Orbital Lifetime & Collision Probability

The probability of CUTE 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 CUTE to be compliant. Requirement 4.5-2 is not applicable to this mission.

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

CUTE 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 shows finds CUTE in its stowed configuration 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

$$\frac{0.069\ m^2}{10.65\ kg} = 0.00648\,\frac{m^2}{kg}$$

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

<u>DAS 3.0 Orbital Lifetime Calculations:</u>
DAS inputs are: 550 km circular orbit with an inclination of ~97.598º at deployment no earlier than January 2021. An area to mass ratio of 0.006476 m^2/kg for the CUTE CubeSat was used. DAS 3.0 yields a 10.98 years orbit lifetime for CUTE in its stowed state and 2.11 years orbit lifetime in its deployed state with an area to mass ratio of 0.02103 m^2/kg.

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 CUTE 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: CUTE High Melting Temperature Material Analysis

Name	Material	Total Mass (kg)	Demise Alt (km)	Kinetic Energy (J)
Solar Panel Hinge	Titanium	.024	0.	0
UHF Antenna	Stainless Steel	.013	0	0
Reaction Wheel Magnets	Iron	.019	74.7	-
Reaction Wheel Spin Mech	Stainless Steel	10.2	71.2	-
Torque Rod Core	Iron	.058	72.4	-
Primary Flexure 1	Titanium	.073	70.4	-
Primary Flexure 2	Titanium	.140	67.7	-
Batteries	Stainless Steel	.270	72.7	-
Washers	Steel A-286	.142	77.5	-
Fasteners	Steel A-286	.628	77.2	-
Secondary mount center	Invar	.012	0	2
Secondary mount sides	Invar	.034	0	3
Spider 1	Invar	.036	0	6
Spider 2	Invar	.036	0	6
Spider 3	Invar	.036	0	6
Spider 4	Invar	.036	0	6

Primary Mount Cylinder	Invar	.056	71.6	-
Central Spire	Invar	.220	67.9	0
Heat Strap	Graphene	.0146	0	3
S-band Antenna Patch	Ceramic	.021	75.6	-

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

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

Section 8: Assessment for Tether Missions

CUTE will not be deploying any tethers.

CUTE 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 launch service provider.

If you have any questions, please contact the undersigned at 321-867-2098.

/original signed by/

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Flight Design Analyst
a.i. solutions/KSC/AIS2

cc: VA-H/Mr. Carney
VA-H1/Mr. Beaver
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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. CUTE 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	CUTE	1		-	10650	237	362	110	-	-	Demise
2	Deployable Solar Arrays	4	Fiberglass	Box	1498	237	340	6	No	-	Demise
3	Solar Panel Hinge	8	Titanium (6 Al-4 V)	Box	24	14	113	5	Yes	3034°	0 km
4	UHF antenna	1	Stainless Steel (generic)	Box	13	32	151	28	Yes	2500°	0 km
5	ADCS Housing	2	Aluminum 6061-T6	Box	506	100	100	50	No	-	Demise
6	ADCS - Reaction Wheel Case	3	Aluminum 6061-T6	Box	51	41	41	17	No	-	Demise
7	ADCS - Reaction Wheel Magnets	24	Iron	Box	19.92	6.4	11	1.9	Yes	2800°	Demise
8	ADCS Reaction Wheel Spin Mech	3	Stainless Steel (generic)	Cylinder	1020	13	41	-	Yes	2500°	Demise
9	Torque Rod Housing	3	Aluminum 6061-T6	Cylinder	5.1	12.2	35	-	No	-	Demise
10	Torque Rod Winding	3	Copper Alloy	Cylinder	54.9	12	33	-	No	-	Demise
11	Torque Rod Core	3	Iron	Cylinder	58.8	9.44	38.1	-	No	2800°	Demise
12	ADCS Star Tracker Housing	1	Aluminum 6061-T6	Box	52	52	53	48	No	-	Demise
13	CUTE Chassis	1	Aluminum 6061-T6	Box	2763	237	362	110	No	-	Demise
14	Detector	1	Alumina	Box	7	20	33	3	No	-	Demise
15	Primary Flexure 1	1	Titanium (6 Al-4 V)	Box	73	20	64	13	Yes	3034°	Demise
16	Primary Flexure 2	1	Titanium (6 Al-4 V)	Box	140	35	66	20	Yes	3034°	Demise
17	Secondary Mirror	1	Zerodur	Box	36	70	70	30	No	-	Demise
18	Primary Mirror	1	Zerodur	Box	1344	82	206	45	No	-	Demise
19	UHF Radio	1	Aluminum 6061-T6	Box	103	57	83	16	No	-	Demise
20	Battery Board	1	Fiberglass	Box	46	33	65	1.5	No	-	Demise
21	Batteries	6	Stainless Steel (generic)	Cylinder	270	18	65	-	Yes	2500°	Demise

22	Antenna Deployment Module	1	Polyimide	Box	80	39	66	30	No	-	Demise
23	Washers	142	Steel A-286	Cylinder	142	15	5	-	Yes	2500°	Demise
24	Fasteners	449	Steel A-286	Cylinder	628.6	3.2	20	-	Yes	-	Demise
25	Wire Harnessing	40	Copper Alloy	Cylinder	40	0.6	400	-	No	-	Demise
26	Connectors	20	Aluminum 6061-T6	Box	20	9	14	6	No	-	Demise
27	Secondary mount center	1	Invar	Box	12.1	30.48	40.132	4.57	Yes	2600°	0 km
28	Secondary Mount Sides	2	Invar	Box	33.8	27.6	35.5	21.59	Yes	2600°	0 km
29	Secondary Spider 1	1	Invar	Flat Plate	36	29.4	118	3	Yes	2600°	0 km
30	Secondary Spider 2	1	Invar	Flat Plate	36	29.4	118	3	Yes	2600°	0 km
31	Secondary Spider 3	1	Invar	Flat Plate	36	29.4	118	3	Yes	2600°	0 km
32	Secondary Spider 4	1	Invar	Flat Plate	36	29.4	118	3	Yes	2600°	0 km
33	Primary Mount Cylinder	1	Invar	Cylinder	56.3	35.5	16.25	-	Yes	2600°	0 km
34	Central Spire	1	Invar	Box	220	45.72	66.04	32.76	Yes	2600°	0 km
35	Spectrograph Housing	1	Aluminum 6061-T6	Box	207	70	83	41	No	-	Demise
36	Grating	1	Zerodur	Box	34	31	31	15	No	-	Demise
37	Grating Back Plate	1	Aluminum 6061-T6	Box	31.9	42.3	42.3	10	No	-	Demise
38	Grating Housing	1	Aluminum 6061-T6	Box	79.3	45	50	38	No	-	Demise
39	Sun Sensors	3	Aluminum 6061-T6	Box	19.5	27	27	9.5	No	-	Demise
40	Heat Strap Block	1	Aluminum 6061-T6	Box	36.3	25	26	25	No	-	Demise
41	Heat Strap	1	Graphene	Box	14.6	23	71	6	Yes	3500°	0 km
42	Shutter	1	Aluminum 6061-T6	Cylinder	10	25.4	11.1	-	No	-	Demise
43	Flat + slit mount	1	Aluminum 6061-T6	Box	17	26	27	17	No	-	Demise
44	Folding Flat Mirror	1	Zerodur	Box	0.4	6	15	2	No	-	Demise
45	Second Fold Mirror	1	Zerodur	Box	11.6	17.68	22.96	11.3	No	-	Demise
46	LEM	1	Copper Alloy	Box	23	27	53	9	No	-	Demise
47	GPS Patch	1	Ceramic	Box	20.6	25.4	25.4	12.7	No	-	Demise
48	GPS Board	1	Fiberglass	Box	6.03	45.7	71.7	1.58	No	-	Demise

49	Battery Board	1	Fiberglass	Box	4.05	32.7	65	1.56	No	-	Demise
50	Inst. Electronics Enclosure	1	Aluminum 6061-T6	Box	185	100	100	68	No	-	Demise
51	Inst. Electronics	2	Fiberglass	Box	53.96	12	87	14	No	-	Demise
52	Power Expansion Board	1	Fiberglass	Box	15	100	104	6.35	No	-	Demise
53	C&DH Board	1	Fiberglass	Box	12.06	100	104	6.35	No	-	Demise
54	Power Board	1	Fiberglass	Box	17.6	100	104	6.35	No	-	Demise
55	Flex Circuitry	1	Copper Alloy	Flat Plate	4.8	90	90	-	No	-	Demise
56	SDR Board	1	Fiberglass	Box	5.8	31	72	1.53	No	-	Demise
57	S-band Antenna Patch	1	Ceramic	Box	68.5	75.9	76.2	4.7	No	-	Demise
58	S-band Board Case	1	Aluminum 6061-T6	Box	38.9	87	87	1.9	No	-	Demise
59	S-band Boards	1	Fiberglass	Box	81.3	65	68	10	No	-	Demise
60	UHF Board	1	Fiberglass	Box	87.6	57	83	10	No	-	Demise
61	UHF Housing	1	Aluminum 6061-T6	Box	103	57	83	16	No	-	Demise