ELVL-2023-0046553
May 4, 2023

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

Signature Page

Jimmy Smith, Analyst, NASA KSC VA-H1

Norman Phelps, Mission Manager, NASA KSC VA-C

National Aeronautics and
Space Administration

John F. Kennedy Space Center, Florida
Kennedy Space Center, FL 32899

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Reply to Attn of: VA-H1

TO: Norman Phelps, LSP Mission Manager, NASA/KSC/VA-C

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

SUBJECT: Orbital Debris Assessment Report (ODAR) for the TRYAD 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 August 2022
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. ODPO Guidance Email: 6U CubeSat Battery Concerns, J.C. Liou to Eric Haddox, 18 May 2021
K. Debris Assessment Software User’s Guide: Version 3.2, NASA/TP-2019-220300

The intent of this report is to satisfy the orbital debris requirements listed in ref. (a) for the TRYAD CubeSat launching on the USSF-62 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 CubeSat will passively reenter, and therefore this ODAR will serve as the End of Mission Plan (EOMP) for this CubeSat.

RECORD OF REVISIONS		
REV	**DESCRIPTION**	**DATE**
0	Original submission	May 2023

Section 1: Program Management and Mission Overview

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

Michael Fogle, PI, Auburn University

The following table summarizes the compliance status of TRYAD, which will be flown on the USSF-62 mission to a 550km sun-synchronous orbit. The current launch date is planned for NET 01/01/2024. DAS version 3.2.3 was used to generate the data provided in this document. TRYAD 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 11.439 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: TRYAD Attributes

CubeSat Names	CubeSat Quantity	CubeSat size (mm)	CubeSat Mass (kg)
TRYAD	2	366 x 226 x 100	9.154

The following pages describe the TRYAD CubeSat.

TRYAD – Auburn University – 6U

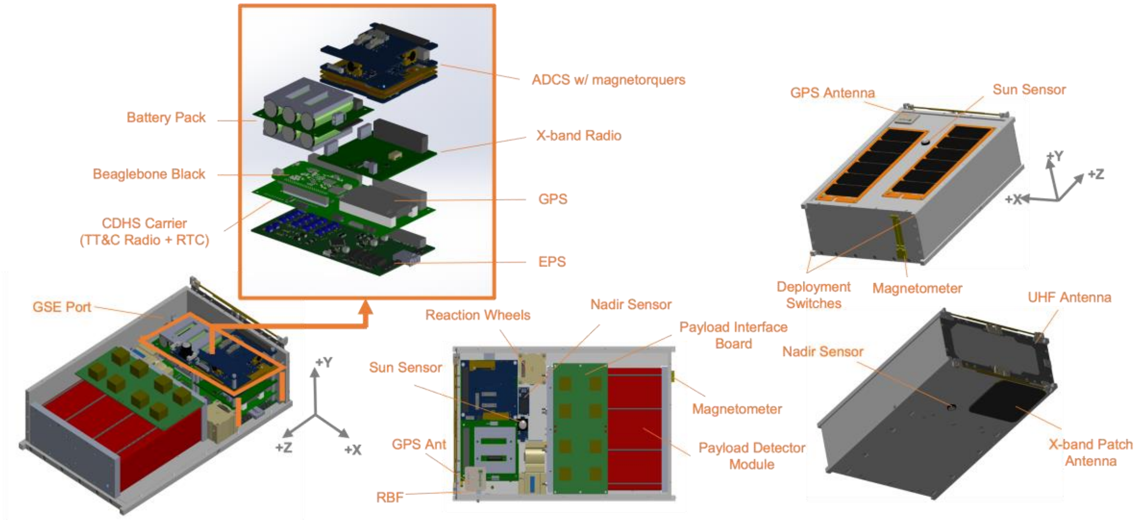

Figure 1: TRYAD Expanded View

Overview

TRYAD is a pair of 6U CubeSats designed to simultaneously measure terrestrial gamma-ray flashes (TGFs) from LEO in order to derive constraints on the electric fields that accelerate the electrons responsible for gamma-ray emissions.

The Payload is a gamma-ray scintillation detector that is comprised of four plastic scintillator bars with silicon photomultiplier (SiPMs) arrays at the end of each bar to detect visible scintillation light produced by gamma-ray interaction with the detector. These detected light pulses are proportional to incident gamma-ray energy.

CONOPS

Upon deployment from the dispenser, TRYAD-1 and TRYAD-2 will power up and start counting down timers. Based on the launch provider Mission Requirements Document, the UHF antenna and magnetometer may be deployed 5 minutes after separation from the dispenser. RF emitters may also be powered on 5 minutes after separation from the dispenser.

Initial UHF TT&C contacts will be made with the Auburn ground station for orbit clarification and TLE uplink. A post-launch assessment of the functions for each spacecraft will be performed.

Following post-launch assessment, science acquisitions will be planned on the ground and time sequences for science acquisition events will be uplinked to each spacecraft.
The spacecraft will nominally Sun track the solar panels and perform TT&C when in line of sight to ground station. During science acquisitions, in the +/- 20 deg latitude regions, the spacecraft will slew to nadir track the payload. Upon completion of the science acquisition, the spacecraft will slew back to nominal Sun tracking. When commanded or sequenced, the spacecraft will slew to track the ground station for X-band downlink of science data.

Differential drag maneuvers will be used for station keeping and to separate the spacecraft in a controlled fashion throughout the mission lifetime.

At end-of-life (EOL) the spacecraft will be commanded into a high drag orientation and the EPS system will be commanded to disable maximum power point tracking (MPPT) charging functions by writing a flag update to the EPS microcontroller FRAM memory (resilient against reset/reboot). This will inhibit any solar panel power from charging the batteries. The batteries will then drain until the EPS system is inoperable. The satellites will then be considered EOL and dormant for re-entry.

Materials

The CubeSat structure is made of Aluminum 6061-T6. The dispenser tabs are manufactured from 7075-T7351 and fastened to the main spacecraft structure. Each spacecraft contains standard commercial off the shelf (COTS) materials, electrical components, PCBs and solar cells. The GPS and high-speed x-band radio use ceramic patch antennas. The payload is primarily comprised of a plastic scintillator material and PCBs.

Hazards

There are no pressure vessels, hazardous or exotic materials.

Batteries

The electrical power system is comprised of six Panasonic 18650 Li-ion cells in a 1S6P configuration. Each 18650 cell has a protection circuit for overcurrent, overvoltage, overcharge. The battery pack has a nominal voltage of 3.6 V and a capacity of 72 Wh. The Panasonic 18650 cells carry a UL listing of MH12210.

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 TRYAD 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 TRYAD.

As discussed in Reference H, 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 TRYAD battery cells are UL certified under MH12210, using UL 1642 testing standards for lithium batteries, which addresses various concerns, including overcharge/over discharge, temperature cycling, shock, vibration, low pressure, overheating, and other concerns.

Limitations in space and mass prevent the inclusion of the necessary resources to disconnect the battery or the solar arrays at EOM. However, a flag in the FRAM flight software will be changed at EOM to break the software link between the batteries and solar panels, rendering the panels unable to further charge the batteries. The charge in the batteries will then continue to dissipate until they are empty.

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4 shows that with a maximum lifetime of 11.461 years maximum, TRYAD 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.

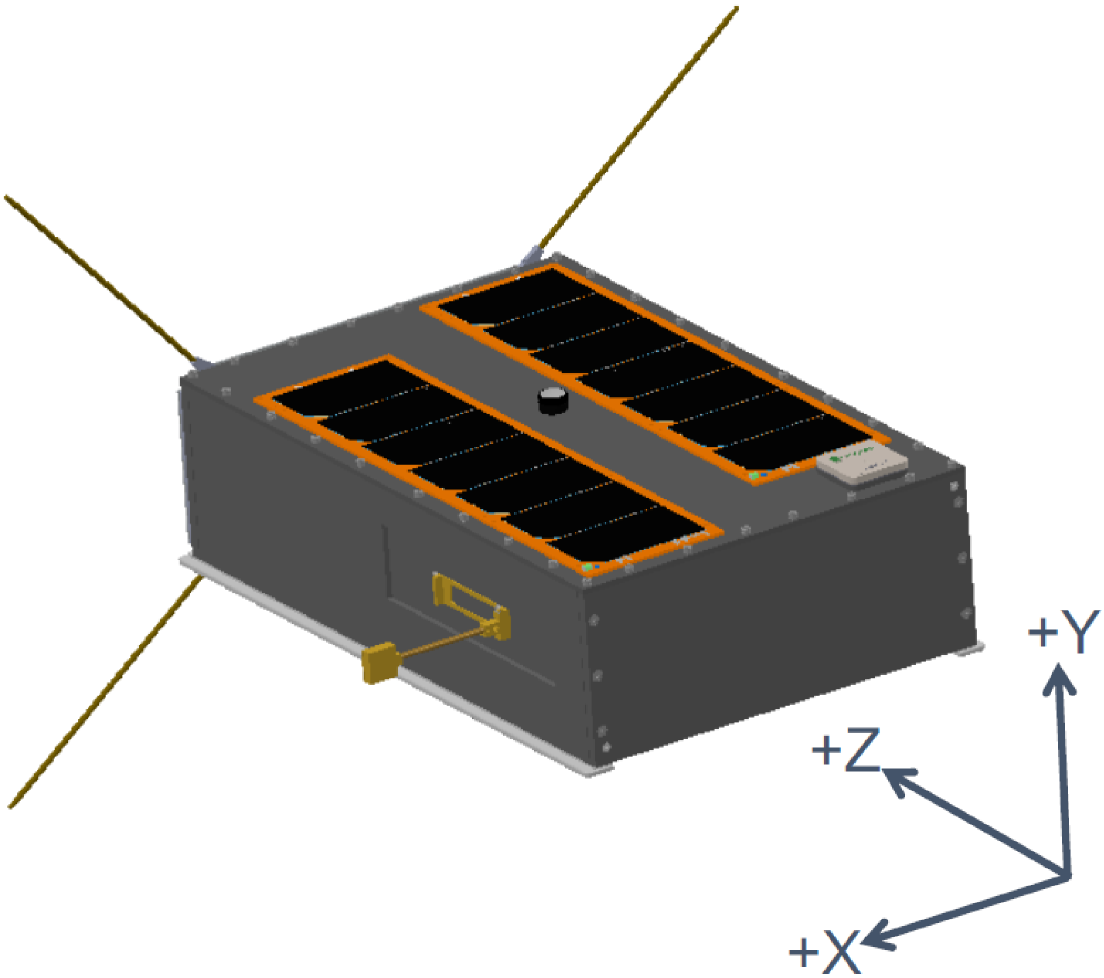

Figure 2: TRYAD Deployed View

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

Equation 1: Mean Cross Sectional Area for Convex Objects

$$\boldsymbol{Mean\ CSA} = \frac{(\boldsymbol{A_{max}} + \boldsymbol{A_1} + \boldsymbol{A_2})}{\mathbf{2}}$$

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 $\boldsymbol{Mean\ CSA} = \frac{\sum \boldsymbol{Surface\ Area}}{\boldsymbol{4}} = \frac{\boldsymbol{2}*[(\boldsymbol{w}*\boldsymbol{l})+(\boldsymbol{w}*\boldsymbol{h})+(\boldsymbol{l}*\boldsymbol{h})]}{\boldsymbol{4}}$
Equation 1. This configuration renders the longest orbital lifetimes 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}. All deployables for TRYAD are of negligible CSA and are therefore ignored. The As-Ejected spacecraft properties will therefore be used for all analyses.

TRYAD's expected orbit at deployment has a 550-km apogee and a 550-km perigee at a 97.6° inclination. With an area to mass ratio of 0.0078 m^2/kg, DAS yields 11.461 years for orbit lifetime for its as-ejected state, which in turn is used to obtain the collision probability. TRYAD is calculated to have a probability of collision of 0.0. Table 3 below provides complete results.

Table 3: CubeSat Orbital Lifetime & Collision Probability

	CubeSat	**TRYAD**
	Mass [kg]	9.15
As-Ejected	**Mean C/S Area [m^2]**	0.0710
	Area-to Mass [m^2/kg]	0.0078
	Orbital Lifetime [yr]	**11.439**
	Probability of Collision	**2.62E-05**

Solar Flux Table Dated 28 March 2023

The probability of TRYAD colliding with debris or meteoroids greater than 10 cm in diameter that are capable of preventing post-mission disposal is 0.00, for any configuration. This satisfies the 0.001 maximum probability requirement 4.5-1.

Assessment of spacecraft compliance with Requirements 4.5-1 shows TRYAD 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

TRYAD will naturally decay from orbit within 12 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.

Calculating the area-to-mass ratio for the worst-case (smallest Area-to-Mass) post-mission disposal finds TRYAD 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

$$\frac{0.0710\ m^2}{9.15\ kg} = 0.0078\frac{m^2}{kg}$$

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: 550-km maximum apogee and 550-km maximum perigee altitudes with an inclination of 96.7º at deployment no earlier than January 2024. An area to mass ratio of ~0.0078 m^2/kg for the TRYAD CubeSat was used. DAS yields a 11.439 years orbit lifetime for TRYAD in its stowed state.

This meets requirement 4.6-1.

Section 7: Assessment of Spacecraft Reentry Hazards

A detailed assessment of the components to be flown on TRYAD 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 Project Office (Reference I)

Table 4: TRYAD High Melting Temperature Material Analysis

Name	Material	Total Mass (kg)	Demise Alt (km)	Kinetic Energy (J)
X-Band Antenna	Ceramic	0.03	0.0	0.81
Reaction Wheels	Brass	0.45	71.8	0.00

The majority of high melting point components demise upon reentry and TRYAD 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
TRYAD	Compliant	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 TRYAD has a zero probability, as none of its components have more than 15J of energy.

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

Section 8: Assessment for Tether Missions

TRYAD 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/

Jimmy D. Smith
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. TRYAD Component List

Row Number	Name	Quantity	Material	Body Type	Unit Mass (kg)	Diameter / Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Point (F)	Survivability (J)
1	TRYAD, 6U	1		Box	9.154	226.3	366.0	100.0	N	-	-
2	Structure Plate (+Y)	1	6061-T6	Plate	1.156	226.3	366.0	8.5	N	-	-
3	Structure Plate (-Y)	1	6061-T6	Plate	1.156	226.3	366.0	8.5	N	-	-
4	Structure Plate (+X)	1	6061-T6	Plate	0.511	100.0	366.0	8.5	N	-	-
5	Structure Plate (-X)	1	6061-T6	Plate	0.511	100.0	366.0	8.5	N	-	-
6	Structure Plate (+Z)	1	6061-T6	Plate	0.223	100.0	226.3	6.0	N	-	-
7	Structure Plate (-Z)	1	6061-T6	Plate	0.223	100.0	226.3	6.0	N	-	-
8	Dispenser tabs	2	7075-T7351	Plate	0.117	16.0	366.0	4.3	N	-	-
9	Magnetometer (Cubespace)	1	6061-T6, PCB	Plate	0.015	16.8	83.3	6.7	N	-	-
10	GPS Antenna (Taoglas)	1	ceramic, PCB	Plate	0.010	35.0	35.0	3.7	Y	3762	0
11	UHF Tranceiver (Endurosat)	1	PCB	Plate	0.090	95.0	88.3	23.2	N	-	-
12	UHF Antenna (Endurosat 2U)	1	Aluminum	Plate	0.210	100.0	228.0	6.5	N	-	-

13	X-band patch antenna (In-house)	1	ceramic	Plate	0.030	100.0	100.0	10.0	Y	3762	0.81
14	Solar Panel (DHV)	2	PCB, Si	Plate	0.252	82.0	300.0	1.6	N	-	-
15	EPS PCB	1	PCB	Plate	0.115	94.5	176.2	18.0	N	-	-
16	Li-ion Cells (Panasonic 18650)	6		Cylinder	0.291	18.0	68.0		N	-	-
17	Battery Pack PCB	1	PCB	Plate	0.025	88.1	94.5	18.0	N	-	-
18	Battery Retainers	2	6061-T6	Plate	0.126	68.0	68.0	5.0	N	-	-
19	CDHS PCB	1	PCB	Plate	0.115	94.5	176.2	18.0	N	-	-
20	Flight Computer (Beaglebone Black)	1	PCB	Plate	0.091	54.0	88.0	19.0	N	-	-
21	GPS (Novatel OEM615)	1	PCB	Plate	0.024	45.7	71.1	11.1	N	-	-
22	X-band Radio PCB	1	PCB	Plate	0.058	88.0	94.5	18.0	N	-	-
23	ADCS (Cubespace) w/ Magnetorquers	1	PCB, copper coils, ferrous rod cores	Box	0.282	88.1	94.5	48.7	N	-	-
24	Sun/Nadir Sensor	2	PCB, lens	Plate	0.060	17.7	41.7	22.9	N	-	-
25	Reaction Wheel	3	Aluminum body, Brass wheel	Box	0.450	46.0	46.0	31.5	N	-	-
26	Payload Interface PCB	1	PCB	Plate	0.200	94.5	176.2	18.0	N	-	-
27	Payload Detector Module, Endcaps	2	6061-T6	Plate	0.350	71.0	184.0	11.5	N	-	-

28	Payload Detector Module, PCB	2	PCB	Plate	0.080	52.0	176.5	2.0	N	-	-
29	Payload Detector Module, SiPM Arrays	8	PCB, Si	Plate	0.120	35.1	43.3	6.8	N	-	-
30	Payload Detector Module, Middle PCB/Frame	1	Al, PCB	Plate	0.058	52.0	180.9	22.0	N	-	-
31	Payload Detector Module, Retainer Shell	1	6061-T6	Box	0.272	179.0	193.9	55.0	N	-	-
32	Payload Detector Module, Scintilator	4	Plastic	Box	1.320	39.3	165.4	51.0	N	-	-
33	Payload Detector Module, Tension Rod	8	Steel	Cylinder	0.077	2.8	200.0		N	-	-
34	Payload Detector Module, Tension Nut	8	Steel	Cylinder	0.004	6.4	2.0		N	-	-
35	Payload Detector Module, Sintered Screw (venting)	1	brass?	Cylinder	0.004	10.0	5.0		Y	1710	0
36	Coarse Sun Sensors	6	PCB	Plate	0.009	3.8	10.8	1.7	N	-	-
37	SD memory card	1	Plastic	Plate	0.002	11.0	15.0	1.0	N	-	-
38	Coin cell Battery (for RTC)	1		Cylinder	0.006	10.0	2.5		N	-	-
39	*Fasteners (~0.5 g/each), Estimate*	150	Steel	Cylnder	0.075				N	-	-

40	*Cables/Connectors, Estimate*	20	Cu, Plastic	Cylinder	0.404				N	-	-