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

Signature Page

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Reply to Attn of: VA-H1

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

FROM: Emily D'Elia, NASA/KSC/VA-H1

SUBJECT: Orbital Debris Assessment Report (ODAR) for the QubeSat 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 3.1, NASA/TP-2019-220300

The intent of this report is to satisfy the orbital debris requirements listed in ref. (a) for the QubeSat CubeSat launching on the VCLS Demo 2 Astra 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	April 2021

Section 1: Program Management and Mission Overview

QubeSat is sponsored by the Human Exploration and Operations Mission Directorate at NASA Headquarters. The Program Executive is Sam Fonder. Responsible program/project manager and senior scientific and management personnel are as follows:

Vidish Gupta, Project Lead, University of California Berkeley

The following table summarizes the compliance status of QubeSat, which will be flown on the VCLS Demo 2 Astra mission. The current launch date is planned for December 15, 2021. QubeSat 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 3.921 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: QubeSat Attributes

CubeSat Names	CubeSat Quantity	CubeSat size (mm)	CubeSat Mass (kg)
QubeSat	1	100.0 x 100.0 x 227.0	2.54

The following pages describe the QubeSat CubeSat.

QubeSat – University of California, Berkeley – 2U

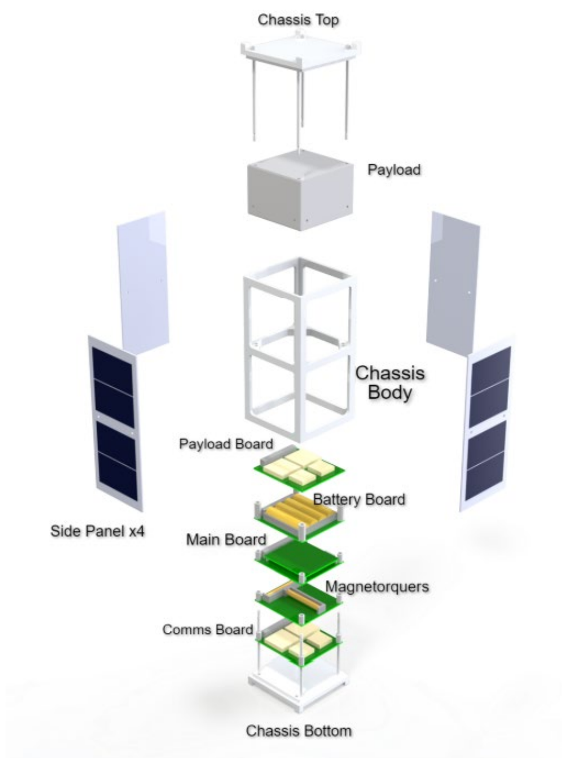

Figure 1: QubeSat Expanded View

Overview

QubeSat will demonstrate a Quantum Gyroscope based on NV- Center Diamonds in space conditions. It will use magnetorquers to create rotation and compare the data from the Quantum Gyroscope to an onboard MEMS gyroscope.

CONOPS

Upon ejection from the dispenser, QubeSat will power up and start counting down timers. At 30 minutes, the antennas will be deployed, then at 45 minutes the UHF beacon will be activated. For the first few passes, the ground station operators will attempt communications to perform checkouts of the spacecraft and calibrate the gyroscope. Approximately 4 days from launch, payload tests will begin and continue for at least 3 months.

Materials

The QubeSat structure is made of Aluminum 7075 T651. It contains a combination of custom and open-source components, electrical components, PCBs, and solar cells. The open-source boards include the PyCubed Main Board, PyCubed Battery Board, and OpenLST. The gyroscope is implemented using a laser, photodiode, near-field RF signal, and a diamond. The radio uses a tape-measure dipole antenna.

Hazards

There are no pressure vessels, hazardous or exotic materials. The spacecraft will use two permanent magnets onboard, the field will be attenuated using Mu-metal shielding.

Batteries

The electrical power storage system consists of common lithium-ion batteries with over-charge/current protection circuitry. The lithium batteries carry the UL-listing number 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 QubeSat 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 QubeSat.

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 3.921 years maximum, QubeSat 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.

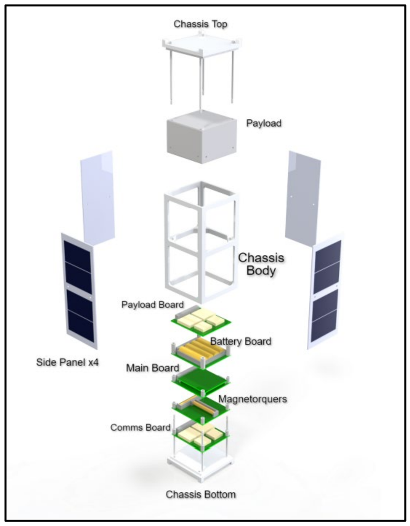

Figure 2: QubeSat Expanded View

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

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 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

QubeSat's expected orbit at deployment is a 500-km circular orbit at a 41° inclination. With an area to mass ratio of 0.0109 m^2/kg, DAS yields 3.921 years for orbit lifetime for its as-deployed state, which in turn is used to obtain the collision probability. QubeSat is calculated to have a probability of collision of 0.0. Table 3 below provides complete results.

CubeSat		QubeSat
	Mass (kg)	2.54
Stowed**	**Mean C/S Area (m^2)**	0.0277
	Area-to Mass (m^2/kg)	0.0109
	Orbital Lifetime (yrs)	**3.921**
	Probability of collision (10^X)	**0.0000**

Solar Flux Table Dated 3/30/2021

**** Deployable antenna area is negligible with respect to lifetime and collision calculations**

Table 3: CubeSat Orbital Lifetime & Collision Probability

The probability of QubeSat 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 QubeSat 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

QubeSat 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.

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

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

Equation 3: Area to Mass

$$\frac{0.0277\ m^2}{2.54\ kg} = 0.0109\,\frac{m^2}{kg}$$

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: 500-km circular orbit with a 41° inclination at deployment no earlier than December 2021. An area to mass ratio of ~0.0109 m^2/kg for the QubeSat CubeSat was used. DAS yields a 3.921 years orbit lifetime for QubeSat 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 QubeSat 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: QubeSat High Melting Temperature Material Analysis

Name	Material	Total Mass (kg)	Demise Alt (km)	Kinetic Energy (J)
Diamond	NV- Diamond (4-50 ppm)	0.001	77.3	-
Filter (Longpass, 600 nm)	UV Fused Silica	0.003	0.0	0.25

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

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

Section 8: Assessment for Tether Missions

QubeSat 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 vehicle provider.

If you have any questions, please contact the undersigned at 321-867-1367.

/original signed by/

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NASA/KSC/VA-H1

cc: VA-H/Mr. Carney
VA-H1/Mr. Beaver
VA-H1/Mr. Haddox
VA-C/Mr. Higginbotham
VA-C/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. QubeSat 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	*QubeSat* (2U)		Al 7075 T651	Box	2536.35	100	100	227	No	-	Demise
2	Main Chassis	1	Al 7075 T651	Box	236.61	98	98	200	No	-	Demise
3	Top Plate	1	Al 7075 T651	Plate	300	100	100	13.5	No	-	Demise
4	Base Plate	1	Al 7075 T651	Plate	300	100	100	13.5	No	-	Demise
5	2U Solar panel, side	4	PCB + XTJ Solar Cells	Plate	293.04	2	99	200	No	-	Demise
6	Magnets	2	EEC 2:17 TC-16 OTC (SmCo)	Ring	300	48.2	48.2	11.4	No	-	Demise
7	Payload Boards	2	PCB + electronic components	Plate	100	96	90	3.2	No	-	Demise
8	Diamond + Magnet Plates	3	Al 7075 T651	Plate	348	96	90	5	No	-	Demise
9	Magnetorquer air coil	1	Copper	Air Coil	46	96	90	6	No	-	Demise
10	Magnetorquer rod	2	Ferrite Core, Copper	Rod	56	18	14	62	No	-	Demise
11	Antenna	1	Stainless Steel	Plate	9	13	304	1	No	-	Demise
12	Openlst	1	PCB + electronic components	Plate	20	60	50	6	No	-	Demise
13	PyCubed Main Board	1	PCB + electronic components	Plate	44	96	90	12	No	-	Demise
14	PyCubed Battery Board	1	PCB + electronic components	Plate	93	96	90	30	No	-	Demise
15	Panasonic NCR18650B	6	Lithium Ion Polymer Battery	Cylinder	285	18.6	18.6	65	No	-	Demise
16	Diamond	1	NV- Diamond (4-50 ppm)	Box	1	3	3	0.15	Yes	7280	Demise
17	Rod Columns	8	Al 7075 T651	Cylinder	20.16	3.2	3.2	115	No	-	Demise
18	Insulating Rod Spacer Type 1	16	G-10/FR4 Garolite	Cylinder	6.256	7.94	7.94	12.7	No	-	Demise
19	Insulating Rod Spacer Type 2	20	G-10/FR4 Garolite	Cylinder	6.68	9.525	9.525	6.35	No	-	Demise
20	Insulating Rod Spacer Type 3	8	G-10/FR4 Garolite	Cylinder	10.68	9.525	9.525	25.4	No	-	Demise

21	Spring Plunger	2	Stainless Steel	Cylinder	0				No	-	Demise
22	Rod-locking Screws	8	Stainless Steel	Cylinder	0.216	3.8	3.8	10	No	-	Demise
23	Electronics Spacers	40	Nylon	Cylinder	5.6	6	6	10	No	-	Demise
24	Rod hex nuts	8	Stainless Steel	Hexagonal Prism	0.816	7	7	3.2	No	-	Demise
25	Thorlabs L520P50 Laser Diode	1	Metal	Cylinder	0.3	5.6	5.6	10	No	-	Demise
26	Hamamatsu S4349 Photodiode	1	Metal	Cylinder	2	9.2	9.2	17.8	No	-	Demise
27	Filter (Longpass, 600nm)	1	UV Fused Silica	Cylinder	3	25	25	3.5	Yes	3110	0.25 J
28	Thorlabs LTN330-A Laser Optic	1	Al 6061-T6, Glass	Cylinder	7	15.7	15.7	21	No	-	Demise
29	Thorlabs C350TMD-B Focusing Optic	1	Glass	Cylinder	30	6.7	6.7	5.8	No	-	Demise
30	Antenna PCB	1	PCB	Plate	3	25	20	2	No	-	Demise
31	Coax Cable	1	RG174	N/A	9	2.79	2.79	50	No	-	Demise
32	Protective Coatings	NA	Type III hard anodized (clear)	NA	NA	NA	NA	NA	No	-	Demise
33	Adhesives	NA	Loctite 271	NA	NA	NA	NA	NA	No	-	Demise