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Orbital Debris Assessment for The OwlSat 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: Mike Perotti, NASA/KSC/VA-H1

SUBJECT: Orbital Debris Assessment Report (ODAR) for the OwlSat 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 OwlSat CubeSat launching on the VCLS Demo-2 Firefly Alpha launch vehicle. 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 launch provider 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	SEP 2021

Section 1: Program Management and Mission Overview

OwlSat 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:

Doug Steinbach, Rice University
Eric Yang, Rice University
Prof. David Alexander, Rice University

The following table summarizes the compliance status of OwlSat, which will be flown on the VCLS Demo-2 Firefly Black mission to a Sun-Synchronous Orbit. The current launch date is planned for 16 June 2022. DAS version 3.1.2 was used to generate the data provided in this document. OwlSat 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 11.96 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: OwlSat Attributes

CubeSat Names	CubeSat Quantity	CubeSat size (mm)	CubeSat Mass (kg)
OwlSat	1	108 x 108 x 113.5	1.379

The following pages describe the OwlSat CubeSat.

OwlSat – Rice University SEDS – 1U

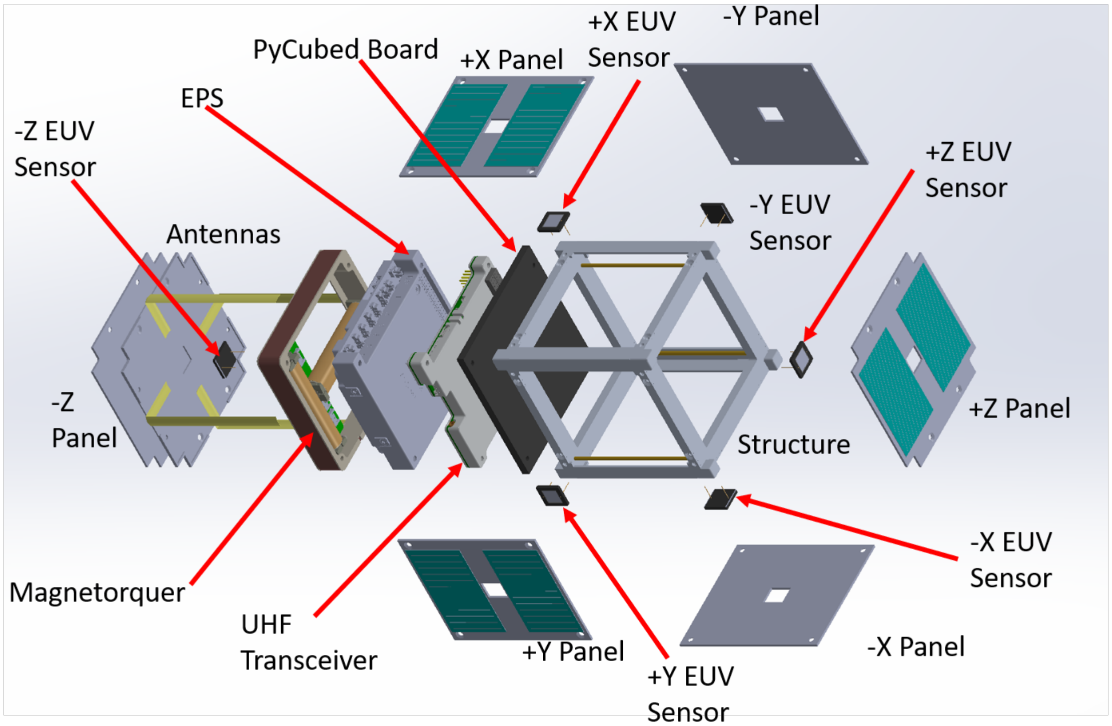

Figure 1: OwlSat Expanded View

Overview

OwlSat is a 1U cube satellite that will measure the extreme ultraviolet (EUV) radiation of low earth orbit. Specifically, the EUV data pre, during, and post solar flares will be studied in conjunction with the GPS location of the satellite. With this raw data a machine learning algorithm will create a model of the cubesat's orbit and how the orbit and drag are affected by changes in EUV radiation.

CONOPS

Immediately upon ejection from the dispenser, the OwlSat will power up and start countdown timers. At 30 minutes, the antennas will be deployed via a burn wire mechanism and spring outwards into their extended positions. At 45 minutes the UHF transceiver will turn on. For the next few passes the OwlSat team will attempt to establish contact with the OwlSat via available ground station networks on the SatNOGS network. During the first week of orbit the OwlSat will continue to ping ground stations to ensure all systems are properly functioning and data can be received. After the first week, the OwlSat will be in its normal operations where it will periodically send data to ground stations for approximately one year.

Materials

The OwlSat chassis will be constructed from 6061 Aluminum that is anodized after machining. The rails that hold all of the electronics will be made of brass. It contains all standard commercial off the shelf (COTS) materials, electrical components, PCBs and solar cells. The primary COTS parts include the PyCubed On-board computer, Endurosat EPS I, Endurosat UHF Transceiver, SatBus MTQ Magnetorquer, Spectrolab XTE-SF Solar Cells, and SXUV5 photodiodes.

Hazards

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

Batteries

The electrical power system that will be used is a single Endurosat EPS I which has one integrated Li-Po battery pack and consists of two Li-Po battery cells connected in parallel. Each battery cell within the battery pack has an integrated Protection Circuit Module (PCM) which prevents over-current, over-charge, and over-discharge. The battery pack voltage and power are 3.7V nominal and 10.2 Wh, respectively. The UL listing number of the Li-Po batteries is 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 OwlSat 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 OwlSat.

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 11.96 years maximum, OwlSat 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.

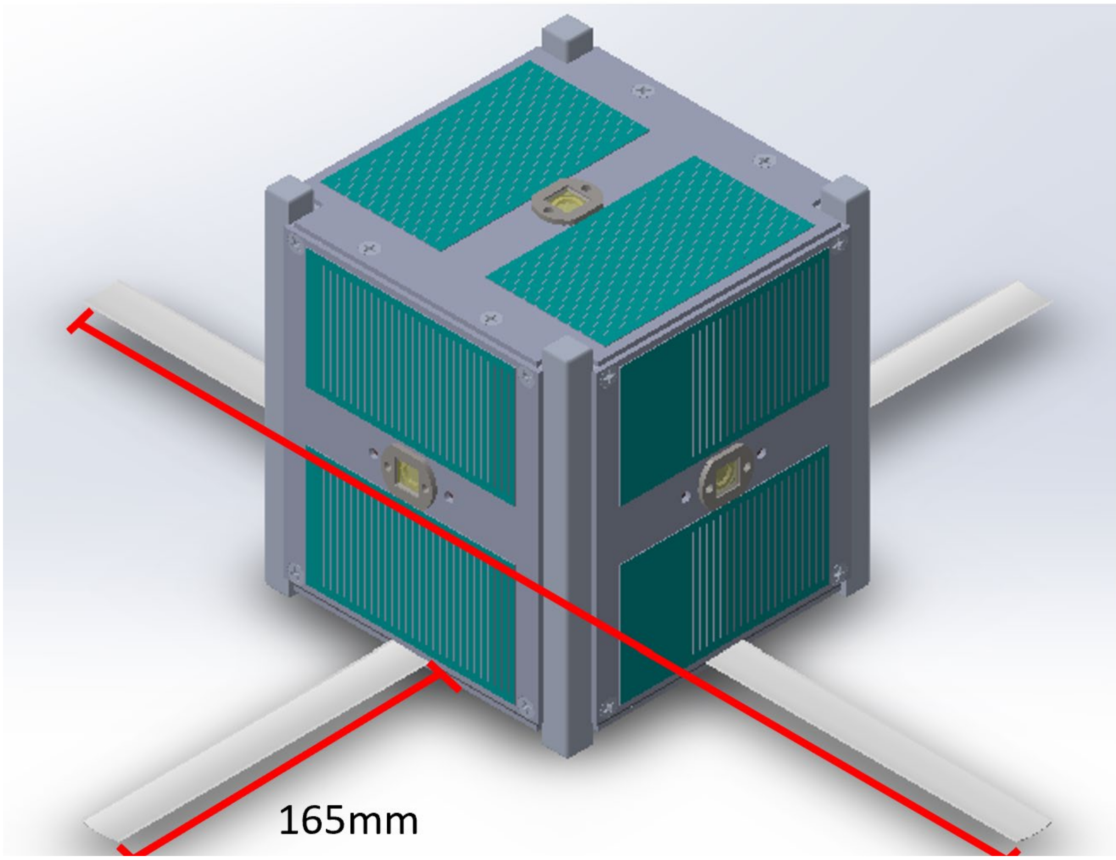

Figure 2: OwlSat Deployed View

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

Equation 1: Mean Cross Sectional Area for Convex Objects

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

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 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

OwlSat's expected orbit at deployment has a 565-km apogee and a 565-km perigee (± 10 km) at a 97.61° inclination. A worst case 575-km circular orbit was assumed. With an area to mass ratio of 0.0131 m^2/kg, DAS yields 11.96 years for orbit lifetime for its as-ejected state, which in turn is used to obtain the collision probability. OwlSat is calculated to have a probability of collision of 5.9 x 10^{-7}. Table 3 below provides complete results.

	CubeSat	OwlSat
	Mass (kg)	1.379
As-Ejected	**Mean C/S Area (m^2)**	0.0181
As-Ejected	**Area-to Mass (m^2/kg)**	0.0131
As-Ejected	**Orbital Lifetime (yrs)**	**11.96**
As-Ejected	**Probability of collision (10^{-7})**	**5.916**
Deployed	**Mean C/S Area (m^2)**	0.0242
Deployed	**Area-to Mass (m^2/kg)**	0.0175
Deployed	**Orbital Lifetime (yrs)**	**8.438**
Deployed	**Probability of collision (10^{-7})**	**4.542**

Solar Flux Table Dated 06/28/2021

Table 3: CubeSat Orbital Lifetime & Collision Probability

The probability of OwlSat colliding with debris or meteoroids greater than 10 cm in diameter that are capable of preventing post-mission disposal is less than 0.000001, for any configuration. This satisfies the 0.001 maximum probability requirement 4.5-1.

Assessment of spacecraft compliance with Requirements 4.5-1 shows OwlSat 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

OwlSat 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 OwlSat 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

$$\frac{0.0181\ m^2}{1.379\ kg} = 0.0131\frac{m^2}{kg}$$

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: 575-km maximum apogee and 575-km maximum perigee altitudes with an inclination of 97.61° at deployment no earlier than 16 June 2022. An area to mass ratio of ~0.0131 m^2/kg for the OwlSat CubeSat was used. DAS yields a 11.96 years orbit lifetime for OwlSat 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 OwlSat 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: OwlSat High Melting Temperature Material Analysis

Name	Material	Total Mass (kg)	Demise Alt (km)	Kinetic Energy (J)
Antenna	Stainless Steel	0.012	0	0.06

The majority of high melting point components demise upon reentry and OwlSat 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
OwlSat	Compliant	1:100,000,000

*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 OwlSat has a 1:100,000,000 probability, as none of its components have more than 15J of energy.

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

Section 8: Assessment for Tether Missions

OwlSat 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 321-205-4667.

/original signed by/

Mike Perotti
Flight Design Analyst
NASA/KSC/VA-H1

cc: VA-H/Mr. Carney
VA-H1/Mr. Beaver
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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. OwlSat Component List

Item Number	Name	Qty	Material	Body Type	Total Mass (g)	Diameter/ Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (F°)	Survivability
1	Owlsat-1U		6061 Aluminum	Box	1378.64	108	108	113.5	No	-	Demise
2	1U +Z Base, Thick plate with 4 rail ends	1	6061 Aluminum	Plate	74.4	100	100	13.5	No	-	Demise
3	1U -Z Base, Thick plate with 4 rail ends	1	6061 Aluminum	Plate	74.2	100	100	14	No	-	Demise
4	1U Corner, anodized L brackets	4	6061 Aluminum	L Bracket	37.6	23	23	100	No	-	Demise
5	PyCubed On-Board Computer	2	PCB + electronic components	Plate	100	100	100	5	No	-	Demise
6	Endurosat EPS I	1	PCB + electronic components	Plate	208	90	96	30	No	-	Demise
7	Photodetector SXUV5	6	Aluminum + sensor	Cylinder	60	9.14	9.14	16.25	No	-	Demise
8	1U Payload Rods	4	Brass	Cylinder	14.44	3	-	94	No	-	Demise
9	Spectrolab XTE-SF CIC Solar Cells	12	PCB + Triple Junction Solar Cell	Plate	252	39.7	69.1	0.1	No	-	Demise
10	NanoAvionics SatBus MTQ Magnetorquer	1	PCB + Copper + Plastic	Plate	205	96	94	17	No	-	Demise
11	Endurosat UHF Transceiver II	1	PCB + Aluminum	Plate	94	90	96	15	No	-	Demise
12	In-house antenna (Carpenters tape)	4	Stainless stell + fiberglass	Plate	12	0.1	165	15	Yes		0 km
13	Hyperion GNSS200 receiver	1	PCB + pin header	Plate	3	15	20	3	No	-	Demise
14	Taoglas AP.35A Patch Antenna	1	PCB + U.FL Connector	Plate	10	35.0	35.0	3.5	No	-	Demise
15	Samsung PRO Endurance microSD Card	1	plastic + silicon	Plate	0.5	14.98	10.92	1.016	No	-	Demise
16	Heilical Insert	40	18-8 Stainless Steel	Cylinder	40				No	-	Demise
17	Structure screws	16	18-8 Stainless Steel	Cylinder	16	5.5	-	7.9	No	-	Demise
18	Solar Panel screws	24	18-8 Stainless Steel	Cylinder	24	5.5	-	9.5	No	-	Demise
19	Antenna fasteners	8	Nylon	Cylinder	4				No	-	Demise
20	Loctite 242	1	Epoxy	N/A	1.50	N/A			No	-	Demise
21	NuSil CV-2566 Epoxy	1	Epoxy	N/A	48	N/A			No	-	Demise
22	VDA / 200GA DuPontTM Kapton®	1	Polyimide Film	Coating	40	84	100	0.05	No	-	Demise

Item Number	Name	Qty	Material	Body Type	Total Mass (g)	Diameter/ Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (F°)	Survivability
23	VDA / 25GA PET / VDA, Embossed and Perforated	1	Aluminum Film	Coating	20	84	100	0.006	No	-	Demise
24	VDA / 100GA DuPont™ Kapton® HN /966 PSA	1	Surface Tape	Tape	20				No	-	Demise
25	Clear DuPont™ Kapton® tap	1	Clear Polyimide Tape	Tape	20				No	-	Demise