ELVL-2021-0045993
March 24, 2021

Orbital Debris Assessment for The CySat-1 CubeSat per NASA-STD 8719.14A

Signature Page

Yusef Johnson, Analyst, a.i. solutions, AIS2

Liam Cheney, Mission Manager, NASA KSC VA-E2

National Aeronautics and
Space Administration

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

ELVL-2021-0045993
March 24, 2021

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 CySat-1 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 3.1.1, NASA/TP-2019-220300

The intent of this report is to satisfy the orbital debris requirements listed in ref. (a) for the CySat-1 CubeSat launching on SpX-23 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 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	March 2021

Section 1: Program Management and Mission Overview

CySat-1 is sponsored by the Human Exploration and Operations Mission Directorate at NASA Headquarters. The Program Executive is Samantha Fonder. Responsible program/project manager and senior scientific and management personnel are as follows:

Peter Papadoupolos, Principal Investigator, Iowa State University

The following table summarizes the compliance status of CySat-1, which will be flown on the SpX-23 mission to the International Space Station. CySat-1 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 1.183 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

Figure 1: Program Milestone Schedule

CySat-1 will be launched as a payload on the Space Falcon 9 launch vehicle executing the SpX-23 mission. The current launch date is projected to be August 18, 2021.

Section 2: Spacecraft Description

Table 2 outlines its generic attributes.

Table 2: CySat-1 Attributes

CubeSat Names	CubeSat Quantity	CubeSat size (mm)	CubeSat Mass (kg)
CySat-1	1	340.5 x 108 x 107.9	2.25

The following pages describe the CySat-1 CubeSat.

CySat-1 – Iowa State University – 3U

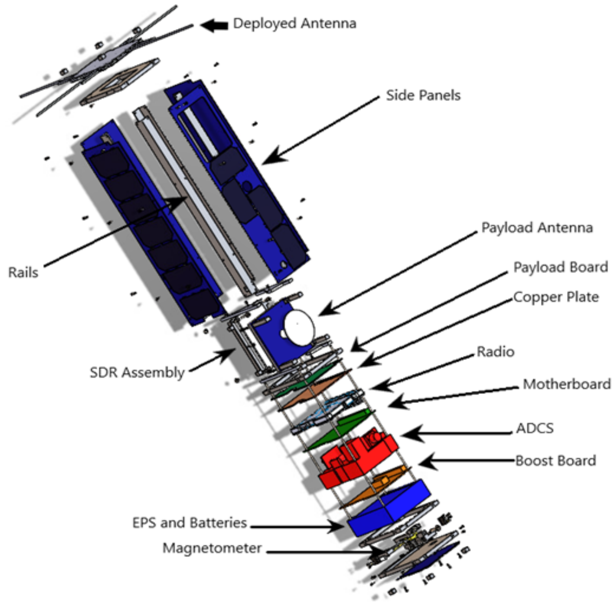

Figure 1: CySat-1 Expanded View

Overview

CySat-1 will operate in a Low Earth Orbit (LEO) environment to test out a state-of-the-art radiometer payload based off a Software Defined Radio (SDR) to observe the Earth and measure the soil moisture.

CONOPS

Once CySat-1 is deployed power will begin flowing and the countdown timers for the deployable antenna and the communication subsystem will initiate. After 45 minutes have passed, the antenna will deploy. The ground station, will then attempt to pick up CySat-1's beacon and establish contact. The satellite will be in a passive mode at this point, and will stay in this mode for roughly the first 24 hours of operations. This involves an ASCII message containing minimal system status information and a welcome message for radio amateurs. A command will then be sent to CySat-1 to ensure health and housekeeping data is gathered. This will continue for no more than a week. Once functions are determined to be nominal, CySat-1 will be transitioned for primary operations and all primary payload routines will be active at this time. Payload activities are desired to continue for at least one year.

Materials

The CySat structure is made of Aluminum 6061-T6. It contains standard commercial off the shelf (COTS) materials, electrical components, PCBs and solar cells.

Hazards

There are no pressure vessels, hazardous or exotic materials.

Batteries

The electrical power storage system consists of Lithium ion batteries with cell overcurrent – charge, cell overcurrent – discharge, cell voltage and cell under – voltage protection circuits on each cell as well as on the entire battery assembly. Additional over – current bus protection and battery under – voltage protection is also provided by the electric power system (EPS). The electrical power system is an EnduroSat EPS I, commonly used by CubeSats launched from the ISS. Qualification tests level and duration follow the ESA standard ECSS-E-ST-10-03C as well as NASA standards contained in GFSC-STD-7000A.

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 CySat-1 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 CySat-1.

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 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 1.183 years maximum, CySat-1 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.

$$\boldsymbol{Mean\ CSA = \frac{\sum Surface\ Area}{4}}$$

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 are 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 is 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

CySat-1 expected orbit at deployment has a 426.4 apogee and a 414.9 km perigee at a 51.6° inclination. With an area to mass ratio of 0.0187 m^2/kg, DAS yields 1.183 years for orbit lifetime for its as-deployed state, which in turn is used to obtain the collision probability. CySat-1 is calculated to have a probability of collision of 0.0. Table 3 below provides complete results.

CubeSat		CySat-1
	Mass (kg)	2.25
As-deployed	Mean C/S Area (m^2)	0.042
	Area-to Mass (m^2/kg)	0.0186
	Orbital Lifetime (yrs)	**1.18**
	Probability of collision (10^X)	**0.0000**

Solar Flux Table Dated 12/16/2020

Table 3: CubeSat Orbital Lifetime & Collision Probability

The probability of CySat-1 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 CySAt-1 to be compliant.

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

Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

CySat-1 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 CySat-1 in its as-released 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

$$\frac{0.042\, m^2}{2.25\, kg} = 0.0186\frac{m^2}{kg}$$

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: 426.4 km maximum apogee 414.9 km maximum perigee altitudes with an inclination of 51.6º at deployment no earlier than August 2021 An area to mass ratio of 0.0186 m^2/kg for the CySat-1 CubeSat was used. DAS yields a 1.18 years orbit lifetime for CySat-1 in its as-released state.

This meets requirement 4.6-1. For the complete list of 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 CySat-1 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 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 less than 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.

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: CySat-1 High Melting Temperature Material Analysis

Name	Material	Total Mass (kg)	Demise Alt (km)	Kinetic Energy (J)
Rods	18-8 Stainless Steel	.080	0	0.7
Standoffs	18-8 Stainless Steel	.084	74.0	-
Separation springs	18-8 Stainless Steel	.0002	77.2	-
Roller Switches	Thermoplastic/Stainless Steel	.004	76.0	-
CubeTorquer	Supra 50 (Iron-Nickel alloy)	.056	0	10.29

The majority of high melting point components demise upon reentry. Surviving components have been shown to have less than 15J of kinetic energy upon impact. CySat-1 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
CySat-1	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 CySat-1 has a 1:0 probability.

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

Section 8: Assessment for Tether Missions

CySat-1 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 CRS provider.

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

/original signed by/

Yusef A. Johnson
Flight Design Analyst
a.i. solutions/KSC/AIS2

cc: VA-H/Mr. Carney
VA-H1/Mr. Beaver
VA-H1/Mr. Haddox
VA-C/Mr. Higginbotham
VA-E2/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. CySat-1 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
-	CySat-1	1	-	-	2.25	100	100	340.5	-	-	Demise
1	CubeSat Structure	1	Aluminum 6061	Box	500	100	100	340.5	No	-	Demise
2	Rods	4	18-8 Stainless Steel	Cylinder	80	2.4	261	---	Yes	2500°	0 km
3	Standoffs	28	18-8 Stainless Steel	Hollow Cylinder	84	8.5	8.5	6.5	Yes	2500°	Demise
4	Fasteners (2M)	50	18-8 Stainless Steel	Screw	40	2	5	---	Yes	2500°	Demise
5	Roller Switches	4	Thermoplastic/Stainless Steel	Box	4	3.378	20	12.268	Yes	-	Demise
6	Separation Springs	2	316 Stainless Steel	Cylinder	0.2	2.843	5.258	---	No	-	Demise
7	Reaction Wheel	1	Brass (flywheel), Alucoat 650 coated Aluminum (housing)	Box	60	28	28	26.2	No	-	Demise
8	Magnetometer - Deployment & Shell	1	Alucoat 650 coated Aluminum	Box	5	15	83	6.3	No	-	Demise
9	Deployable Magnetometer - Boom	1	Brass	Box	2	15	83	6.3	No	-	Demise
10	Course Sun Sensor	6	FR4 - Elpemer AS 2467	Box	6	1.3	3.4	0.45	Yes	-	Demise
11	CubeTorquer (magnetorquer)	2	Supra 50 (Core), Alucoat 650 Aluminum (caps), Enamel coated copper (windings)	Cylinder with box caps	56	13.5	60	18	No	2264°	0 km
12	Cubecoil (magnetorquer)	2	Alucaot 650 Aluminum (body), Enamel coated copper (windings)	Plate	92	90	96	8	No	-	Demise
13	Cube Sense (fine sun sensor & nadir sensor, PCB)	1	FR4 - Elpemer AS 2467	Plate	80	90	96	35	No	-	Demise
14	CubeComputer (ADCS computer)	1	FR4 - Elpemer AS 2467	Plate	56	90	96	10	No	-	Demise
15	Cubecontrol	1	FR4 - Elpemer AS 2467	Plate	60	90	96	30	No	-	Demise
16	Copper plate	1	Copper-plated FR4	Plate	80	90	96	1.6	No	-	Demise

17	Battery (inside EPS)	1	Lithium-Ion Polymer	Box	96.7	90	98	33	No	-	Demise
18	EnduroSat EPS I Electronic Power System (EPS)	1	PCB Material (FR4)	Box	181.3	90	98	33	No	-	Demise
19	XTJ Prime Solar Cells	26	PCB Material (FR4)	Rectangle w/ cropped corners	56.68	6.91	3.97	0.225	No	-	Demise
20	PCB	1	FR-4 Substrate	Box	54	96.52	90.17	1.6	No	-	Demise
21	Linear Voltage Regulator - AP7313	1	Silica(Amorphous)A	Integrated Circuit	0.008	2.4	2.9	1.025	No	-	Demise
22	Buffer - SN74LS125ADR	7	Silica(Amorphous)A	Integrated Circuit	0.903	8.2	10.5	2	No	-	Demise
23	Buffer - PCA9517AD118	2	Silica(Amorphous)A	Integrated Circuit	0.149	6.2	5	1.75	No	-	Demise
24	Software-Defined Radio	1	Copper, Rogers 4003, FR4 370HR, stainless steel, etc.	Box	260	95	83	10	No	-	Demise
25	Payload Board	1	PCB layers, copper, etc	Plate	68.15	90.17	95.89	1.27	No	-	Demise
26	Payload Antenna, braces	1	FR4 - Elpemer AS 2467	Plate, Box	75	91	91	41	No	-	Demise
27	EnduroSat UHF Antenna	1	Aluminum, SMA	Plate	85	98	98	5.7	No	-	Demise
28	EnduroSat UHF Transceiver	1	IPC-A-610E Class 3, Aluminum 6061	Box	94	89	95	23.2	No	-	Demise
29	EnduroSat Flight Computer(OBC)	1	PCB Material (FR4)	Plate	58	85	95	1.6	No	-	Demise
30	Sun Sensor Wires	5	Nickel Coated Copper (PTFE Jacket)	Cylinder	5	0.8	375	---	No	-	Demise
31	Magnetometer Wire	1	Nickel Coated Copper (PTFE Jacket)	Cylinder	1.5	1.2	100	---	No	-	Demise
32	RBF Pin Wire	1	Nickel Coated Copper (PTFE Jacket)	Cylinder	1	0.9	148	---	No	-	Demise
33	Side Panel Power Cables	5	Nickel Coated Copper (PTFE Jacket)	Cylinder	5	1.25	203	---	No	-	Demise
34	Antenna Release Cable	1	Nickel Coated Copper (PTFE Jacket)	Cylinder	1	1	125	---	No	-	Demise
35	Coaxial Cables	2	Copper Core with PTFE Jacket	Cylinder	4	2.5	204	---	No	-	Demise

36	Roller Switch Wires	2	Nickel Coated Copper (PTFE Jacket)	Cylinder	2	1.6	104	---	No	--	Demise